Risk and Protective Factors for Cancer Mortality among United States Service Members and Veterans (2001–2018)

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ABSTRACT

Background: Prior research linking military factors with cancer-specific mortality has shown inconsistent findings, with few studies examining these associations among U.S. service members and veterans who served in Operation Iraqi Freedom/Operation Enduring Freedom conflicts.

Methods: Cancer mortality between 2001 and 2018 was ascertained from the Department of Defense Medical Mortality Registry and National Death Index for 194,689 Millennium Cohort Study participants. Cause-specific Cox proportional hazard models were used to examine links between military characteristics and cancer mortality [overall, early (<45 years), and lung].

Results: Compared with individuals who deployed with no combat experiences, non-deployers had a greater risk of overall [HR = 1.34; 95% confidence interval (CI) = 1.01–1.77] and early cancer mortality (HR = 1.80; 95% CI = 1.06–3.04). Enlisted individuals had a greater risk of lung cancer mortality compared with officers (HR = 2.65; 95% CI = 1.27–5.53). No associations by service component, branch, or military occupation and cancer mortality were observed. Higher education was associated with reduced overall, early and lung cancer mortality risk and smoking and life stressors were associated with elevated overall and lung cancer mortality risk.

Conclusions: These findings are consistent with the healthy deployer effect in which military personnel who were deployed tend to be healthier than those who did not deploy. Further, these findings highlight the importance of considering socioeconomic factors, such as military rank, that may have long-term implications for health.

Impact: These findings highlight military occupational factors that may predict long-term health outcomes. Additional work is necessary to investigate more nuanced environmental and occupational military exposures and cancer mortality.

Environmental and occupational exposures are salient risk factors for cancer mortality (1, 2), the second most common cause of death in the United States. The World Health Organization estimated in 2008 that 19% of all cancer deaths worldwide are attributable to environmental exposures (e.g., tobacco smoke, ionizing radiation), which result in 1.3 million deaths each year (3). Military service, in particular, exposes personnel to a multitude of environmental and occupational hazards such as high levels of psychological stress, increased exposure to sunlight and other forms of radiation, and toxicants (e.g., asbestos, burn pit emissions, solvents; refs. 1, 4–7). Exposures to these hazards may vary by military characteristics or experiences such as service branch, rank, occupational specialty, deployment history, or combat experience. For example, female service members who deployed during the Vietnam War had greater risk of mortality from certain types of cancer than those who were not deployed in Vietnam (8). Similarly, Korean War era service members who were electronic technicians in Navy aviation squadrons had greater risk of cancer mortality (e.g., nonlymphocytic leukemia) than those who were in other occupational specialties (9). However, other studies examining associations between military service characteristics and cancer incidence, or mortality observed null associations (10–12). The heterogeneity in prior findings regarding relationships between military characteristics and cancer mortality may be attributed, in part, to these studies' narrow focus on specific subpopulations, such as personnel who served in particular occupations or during certain conflicts. In addition, a majority of prior work examining cancer mortality in military populations has focused on Vietnam (6, 8, 13, 14) or Gulf War (4, 10, 12, 15) veterans, with little focus on populations serving in recent conflicts, such as Operation Iraqi Freedom/Operation Enduring Freedom (OIF/OEF). Prior cancer mortality research which used service members from previous conflicts, such as the Vietnam War, may not be comparable with samples of OEF/OIF veterans due to unique recruitment methods in each population (i.e., draftee versus volunteer forces). Draftees may more closely mirror a random sample of military-age men whereas volunteer forces are a non-random, self-selected population that may differ on important sociodemographic characteristics (e.g., race, ethnicity, sex/gender, educational attainment, socioeconomic status). Contemporary cohorts of service members and veterans may also be fundamentally different than previous age cohorts due to distinct occupational and environmental exposures, health-related behaviors and experiences related to cancer onset.

Understanding the relationship between military service characteristics and cancer mortality is critical to informing the development of health promotion programs and interventions targeted to service members and veterans at higher risk. The current study evaluated the association between military characteristics (service component, rank, service branch, occupation, deployment, and combat experience) and overall cancer mortality in a large population-based sample of U.S.

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service members and veterans between 2001 and 2018 who predominantly served in OIF/OEF conflicts. As lung cancer is the most common cause of cancer mortality in the U.S. population (16), the current study also examined risk and protective factors for lung cancer mortality. In addition, as the etiology of cancer in adolescent and younger adult populations may be distinct from cancers that develop later in life (e.g., biological and genetic features, environmental exposures, delays in diagnosis, etc.; ref. 17), the current study examined risk and protective factors for early cancer mortality (death due to cancer before age 45).

Materials and Methods

Participants and procedure

Data were drawn from the Millennium Cohort Study, the largest and longest running prospective cohort study of U.S. service members and veterans. Between 2001 and 2013, 4 separate cohorts of service members (referred to as "panels") were randomly selected from active military rosters and invited to enroll in the Millennium Cohort Study, with over-sampling of certain subgroups such as women and reservists (18). A total of 201,619 participants completed a baseline survey at the time of enrollment and additional follow-up surveys every 3 to 5 years thereafter (waves). Participants were selected from all service branches and components and included service members and veterans who mainly served during the OIF/OEF conflicts (19). The study protocol was approved by the Naval Health Research Center (NHRC) institutional review board (IRB; NHRC.2000.0007) and all participants voluntarily provided written, informed consent. The study was conducted in accordance with the U.S. Common Rule and followed the Reporting of studies Conducted using Observational Routinely Collected Data (RECORD) reporting guideline. Participants who indicated any prior history of cancer diagnosis at study entry ($n = 2{,}528$) or who were missing information about prior cancer diagnosis at study entry ($n = 4{,}402$) were excluded from the analyses, leaving an eligible analytic study population of 194,689 participants.

Measures

Demographic characteristics such as birth decade cohort (i.e., calculated from year of birth), sex, race, and ethnicity were obtained for all participants from Defense Manpower Data Center (DMDC) personnel files. Marital status at baseline and highest achieved education level were self-reported on the Millennium Cohort Study survey. Enrollment panel was based on when the participant was recruited into the Millennium Cohort Study (Panel 1: 2001–2003, Panel 2: 2004–2006, Panel 3: 2007–2008, Panel 4: 2011–2013).

Military characteristics obtained from DMDC included service component, service branch, rank, and occupation at baseline. Deployment history in support of OEF/OIF across the study period was obtained from DMDC and was combined with a 5-item self-reported assessment of combat experiences (e.g., witnessing a person's death) measured at each baseline or follow-up survey (20). Combat/deployment experiences were operationalized as a 3-level categorical variable: not deployed, deployed without combat, and deployed with combat.

Health-related characteristics were represented by physical health, mental health, and health behaviors. *Physical health-related quality of life* was measured at baseline by the physical component score (PCS) of the 36-item Short Form Health Survey for Veterans (21). *Body mass index* (BMI) was calculated from self-reported height and weight, with obesity defined as ever reporting a BMI ≥ 30 kg/m^2. *Risky drinking* was defined as ever screening positive for heavy weekly drinking (14+ drinks per week for men, 7+ drinks per week for women) or heavy episodic drinking (5+ drinks for men, 4+ drinks for women in one given day of the week; refs. 22, 23). *Ever smoking* was defined via participant self-report of smoking at least 100 cigarettes in their lifetime. Six *life stressors* (e.g., divorce, financial problems) from the modified Holmes and Rahe Social Readjustment Rating Scale (24) were summed across all available waves and represented by a 3-level categorical variable (0, 1, 2+ life stressors). *Long sleep duration* was assessed with a single item and defined as ever sleeping 9 or more hours on average per night in the past month at any wave (25, 26). *Probable posttraumatic stress disorder* (PTSD) was assessed using the 17-item PCL-C (27) at each survey wave and categorized using the DSM-IV specific criteria. *Probable depression* was assessed using the PHQ-8 (28) at each survey wave, a validated screening instrument based on DSM-IV diagnostic criteria.

Cancer death was assessed during the study period (July 1, 2001–December 31, 2018) from two data sources: (i) the Department of Defense Medical Mortality Registry maintained by the Mortality Surveillance Division of the Armed Forces Medical Examiner System (AFMES) and (ii) National Death Index (NDI) records collected through the Suicide Data Repository maintained by the Defense Suicide Prevention Office. NDI records report International Classification of Diseases (ICD)-10 codes for cause of death. AFMES records more detailed information describing manner of death, description of death, details of cause, and underlying cause. In cases in which data was available from both NDI and AFMES and were discrepant, AFMES was given priority unless it was listed as "Pending." Cancer mortality was identified as the primary cause of death based on the following codes: 'C00' – 'C97' (NDI), or '0590' – '1080' (AFMES).

Additional analyses examined early cancer mortality (under the age of 45 years) and lung-cancer mortality as outcomes of interest. In early cancer mortality analyses, participants were censored at 45 years old. Lung cancer mortality was identified based on the following codes listed as the cause of death: 'C33', 'C34' (NDI), or '0730' (AFMES).

Analytic strategy

Cause-specific Cox proportional hazards models were used to estimate HRs and corresponding 95% confidence intervals (CI) for cancer mortality. Consistent with previous research recommending age rather than time-on-study as the time scale for epidemiologic research (29–31), person-days for each participant were calculated from their date of birth to the date of death or end of the follow-up period (December 31, 2018), whichever occurred first. To further account for age and cohort effects, all models were stratified by birth decade cohorts (see **Table 1**). Models were run hierarchically initially examining demographic characteristics (Model 1), and subsequently adding military characteristics (Model 2), and health-related characteristics (Model 3) into the model. For inclusion into each model, participants must have complete data for all variables in that model. The proportional hazard assumption was initially tested with Schoenfeld residuals and due to large sample size, potential violations were further investigated with a comparison of model fit [i.e., Bayesian information criterion (BIC)] with and without interactions with time. Interactions with time were retained in the model if the variable indicated strong evidence of a proportional hazard violation (Δ BIC ≥ 6; ref. 32).

Primary analyses estimated effects for overall cancer mortality while additional analyses examined early cancer mortality and lung cancer mortality as outcomes of interest. Due to potential competing risks of non-cancer related deaths and in order to test the robustness of our findings (33), primary models were rerun using Fine-Gray

Table 1. Demographic, military characteristics, health and health behaviors, and cancer deaths, Millennium Cohort Study, 2001–2018.

	Total population ($n = 194,689$)		Cancer deaths ($n = 661$)	
	N	**Col %**	***N***	**Col %**
Birth decade cohort				
Pre-1960	16,007	8.2	357	54.0
1960–1969	31,494	16.2	194	29.4
1970–1979	47,422	24.4	67	10.1
1980 or later	99,766	51.2	43	6.5
Sex				
Male	135,371	69.5	481	72.8
Female	59,318	30.5	180	27.2
Race and ethnicity				
Asian/Pacific Islander/American Indian/Multiracial	13,785	7.1	32	4.8
Black, Non-Hispanic	23,871	12.3	85	12.9
Hispanic	15,429	7.9	40	6.1
White, Non-Hispanic	141,604	72.7	504	76.3
Marital status				
Single	66,884	34.4	87	13.2
Currently married	106,053	54.5	452	68.4
Widowed/Divorced/Separated	21,744	11.2	122	18.5
Highest achieved education level				
High School Diploma or Less	25,476	13.1	81	12.3
Some College	70,788	36.4	218	33.0
Associate's or Bachelor's	68,237	35.1	234	35.4
Master's, Doctorate or Professional Degree	30,185	15.5	128	19.4
Service component				
Reserve/National Guard	65,754	33.8	404	61.1
Active Duty	128,935	66.2	257	38.9
Service branch				
Army	87,018	44.7	298	45.1
Navy/Coast Guard	34,720	17.8	135	20.4
Marine Corps	17,563	9.0	22	3.3
Air Force	55,388	28.5	206	31.2
Military rank				
Enlisted	161,824	83.1	516	78.1
Officer	32,865	16.9	145	21.9
Military occupation				
Combat Specialist	33,190	17.1	100	15.1
Functional Support	37,062	19.0	170	25.7
Health Care	21,638	11.1	78	11.8
Other	102,799	52.8	313	47.4
Combat/Deployment				
Not Deployed	81,153	41.7	465	70.4
Deployed, No Combat	38,417	19.7	60	9.1
Deployed with Combat	73,778	37.9	135	20.4
Enrollment panel				
Panel 1 (2001–2003)	74,391	38.2	579	87.6
Panel 2 (2004–2006)	29,145	15.0	41	6.2
Panel 3 (2007–2008)	42,235	21.7	29	4.4
Panel 4 (2011–2013)	48,918	25.1	12	1.8
Ever risky drinking				
No	66,608	34.2	304	46.0
Yes	123,151	63.3	352	53.3
Ever life stressors				
No life stressors	92,939	47.7	172	26.0
1 life stressors	47,499	24.4	193	29.2
2 or more life stressors	52,179	26.8	293	44.3
Physical Component Score (PCS)				
Lowest 15th percentile	28,170	14.5	124	18.8
Middle 70th percentile	133,196	68.4	449	67.9
Highest 15th percentile	28,760	14.8	75	11.4
Ever classified as obese				
No	145,561	74.8	478	72.3
Yes	48,495	24.9	179	27.1

(Continued on the following page)

Table 1. Demographic, military characteristics, health and health behaviors, and cancer deaths, Millennium Cohort Study, 2001–2018. (Cont'd)

	Total population ($n = 194,689$)		Cancer deaths ($n = 661$)	
	N	Col %	*N*	Col %
Ever smoker				
No	103,387	53.1	258	39.0
Yes	88,205	45.3	393	59.5
Ever long sleep duration (9+ hours)				
No	170,552	87.6	552	83.5
Yes	22,488	11.6	107	16.2
Ever screened for probable PTSD (PCL-C)				
No	163,943	84.2	560	84.7
Yes	29,587	15.2	98	14.8
Ever screened for probable depression (PHQ-8)				
No	173,305	89.0	590	89.3
Yes	21,014	10.8	71	10.7
Ever physical activity (150+ min/week)				
No	28,474	14.6	142	21.5
Yes	143,584	73.8	392	59.3
Ever sedentary activity (8+ hours)				
No	115,597	59.4	360	54.5
Yes	60,237	30.9	178	26.9

Note: Column percentages rounded to the 1st decimal place and may not equal 100% due to missing data. Highest achieved education level, combat experience, life stressors, ever obesity, ever smoker, ever long sleep duration, ever probable depression, ever PTSD, and ever risky drinking were assessed based on all available survey waves 2001 through 2016. Ever physical activity and ever sedentary activity were assessed based on all available survey waves 2004 through 2016. Missing data for marital status ($n = 8$), education ($n = 3$), combat/deployment ($n = 1,341$), risky drinking ($n = 4,930$), life stressors ($n = 2,072$), PCS ($n = 4,563$), smoking status ($n = 3,097$), obesity ($n = 633$), sleep duration ($n = 1,649$), probable PTSD ($n = 1,159$), probable depression ($n = 370$), physical activity ($n = 22,631$), sedentary activity ($n = 18,855$).

subdistribution hazard models. All analyses were conducted using SAS software, version 9.4 (SAS Institute Inc, Cary, NC).

Data availability

The datasets analyzed during the current study are not publicly available due to security protocols and privacy regulations, but they may be made available on reasonable request by the NHRC IRB.

Results

Descriptive statistics are reported in **Table 1**. The mean age at death or at end of the follow-up period, whichever came first, was 42.1 (SD = 10.2 years; range = 20.1–84.2 years). Of the eligible 194,689 participants, 2,800 died from any cause and 661 died from cancer between 2001 and 2018. The most common causes of cancer-related death in the study population were lung cancer ($n = 121$), colorectal cancer ($n = 69$), and brain cancer ($n = 62$). All participants with a cancer-related death had separated from military service. No variable showed strong evidence of a proportional hazard assumption violation. Frequencies for health-related factors and self-reported medical conditions across combat/deployment experience are presented in Supplementary Table S1.

Overall cancer mortality

Unadjusted and adjusted HRs and 95% CIs for overall cancer mortality are reported in **Table 2**. For demographic characteristics, individuals with lower education levels (i.e., a high school degree or less, some college) showed greater overall cancer mortality risk whereas those with a master's degree or higher had lower overall cancer mortality risk compared with those with an associate's or bachelor's degree. In addition, participants recruited in Panel 4 showed lower overall cancer mortality risk compared with those recruited in Panel 1. Sex and marital status were associated with overall cancer mortality in unadjusted models, but these effects were no longer significant in fully adjusted models. Race and ethnicity were not associated with overall cancer mortality in unadjusted or adjusted models.

For military characteristics, non-deployed individuals appeared to have a 34% greater overall cancer mortality risk compared with those who were deployed with no combat. No difference was found between those who deployed with combat and those who deployed without combat. In addition, enlisted individuals had approximately 67% greater overall cancer mortality risk than officers in unadjusted models, however, this effect was no longer significant after adjusting for demographic and other military characteristics. Service component, service branch, and military occupation were not associated with overall cancer mortality in unadjusted or adjusted models.

For health-related characteristics, individuals who experienced 1 or 2+ life stressors had greater overall cancer mortality risk compared with those who reported none. Individuals who were classified as obese showed lower overall cancer mortality risk compared with individuals who were never classified as obese. Individuals who ever reported smoking had greater overall cancer mortality risk compared with nonsmokers. Both PCS and long sleep duration were associated with overall cancer mortality in unadjusted models, however, these effects were no longer significant in adjusted models. Risky drinking, probable PTSD, and probable depression were not significantly associated with overall cancer mortality in unadjusted or adjusted models.

Early cancer mortality

Of the 661 observed cancer-related deaths, 151 occurred among participants under the age of 45. Unadjusted and adjusted HRs and 95% CIs for early cancer mortality are reported in **Table 3**.

For demographic characteristics, individuals who reported being single had greater early cancer mortality risk than those who reported

Table 2. Unadjusted and adjusted effect estimates for overall cancer mortality.

	Unadjusted Models (n = 194,689, 661 deaths) Unadjusted HR (95% CI)	Model 1 (n = 194,678, 661 deaths) Adjusted HR (95% CI)	Model 2 (n = 193,337, 660 deaths) Adjusted HR (95% CI)	Model 3 (n = 183,622, 629 deaths) Adjusted HR (95% CI)
Sex (Ref: Female)				
Male	**84 (0.70–0.99)**	**.78 (0.65–0.94)**	**.82 (0.67–0.99)**	.91 (0.74–1.12)
Race and ethnicity (Ref: White, Non-Hispanic)				
Asian/Pacific Islander/American Indian/Multiracial	.92 (0.64–1.32)	.93 (0.65–1.33)	.92 (0.64–1.32)	.96 (0.67–1.38)
Black, Non-Hispanic	1.01 (0.80–1.27)	.92 (0.73–1.16)	.91 (0.72–1.16)	.94 (0.73–1.21)
Hispanic	1.02 (0.74–1.40)	.96 (0.70–1.33)	.96 (0.70–1.33)	.99 (0.70–1.38)
Marital status (Ref: Married)				
Single, never married	1.25 (0.98–1.60)	1.18 (0.92–1.52)	1.19 (0.92–1.53)	1.29 (0.99–1.67)
Separated, divorced, or widowed	**1.27 (1.04–1.55)**	1.16 (0.94–1.42)	1.15 (0.93–1.41)	.96 (0.77–1.20)
Highest achieved education level (Ref: Associate's or Bachelor's degree)				
High school diploma or less	**1.85 (1.43–2.38)**	**1.91 (1.48–2.47)**	**1.82 (1.40–2.37)**	**1.66 (1.26–2.19)**
Some college	**1.44 (1.20–1.73)**	**1.46 (1.22–1.76)**	**1.41 (1.16–1.70)**	**1.36 (1.12–1.65)**
Master's degree or higher	**.70 (0.57–0.87)**	**.70 (0.56–0.86)**	**.75 (0.59–0.97)**	**.76 (0.59–0.98)**
Enrollment panel (Ref: Panel 1)				
Panel 2	1.15 (0.80–1.66)	1.14 (0.80–1.65)	1.22 (0.84–1.76)	1.17 (0.80–1.71)
Panel 3	.99 (0.64–1.56)	1.03 (0.66–1.61)	1.13 (0.72–1.78)	1.17 (0.74–1.84)
Panel 4	**.44 (0.24–0.83)**	**.48 (0.26–0.90)**	.53 (0.28, 1.01)	**.47 (0.23–0.95)**
Service component (Ref: Reserve/National Guard)				
Active duty	.93 (0.79–1.11)	—	1.03 (0.86–1.24)	1.02 (0.84–1.23)
Service branch (Ref: Air Force)				
Army	.96 (0.80–1.15)	—	.92 (0.76–1.10)	.90 (0.75–1.09)
Marine Corps	1.19 (0.96–1.49)	—	1.10 (0.88–1.37)	1.13 (0.90–1.42)
Navy/Coast Guard	1.03 (0.66–1.61)	—	.92 (0.58–1.46)	.95 (0.60–1.52)
Military rank (Ref: Officer)				
Enlisted	**1.67 (1.39–2.01)**	—	1.16 (0.91–1.49)	1.08 (0.84–1.39)
Military occupation (Ref: Combat Specialist)				
Functional support	1.20 (0.94–1.54)	—	1.01 (0.78–1.31)	.98 (0.75–1.28)
Health care	.97 (0.72–1.30)	—	.97 (0.71–1.33)	.99 (0.72–1.36)
Other	1.21 (0.97–1.52)	—	1.03 (0.82–1.29)	1.01 (0.80–1.28)
Deployment/Combat (Ref: Deployed, No Combat)				
Deployed, with Combat	.88 (0.65–1.19)	—	.95 (0.70–1.29)	.86 (0.63–1.18)
Not Deployed	**1.46 (1.11–1.92)**	—	**1.46 (1.11–1.94)**	**1.34 (1.01–1.77)**
Ever risky drinking (Ref: No)				
Yes	1.04 (0.89–1.22)	—	—	.99 (0.84–1.17)
Ever life stressors (Ref: No Life Stressors)				
1 life stressors	**1.37 (1.12–1.69)**	—	—	**1.32 (1.06–1.64)**
2 or more life stressors	**1.60 (1.33–1.94)**	—	—	**1.53 (1.23–1.90)**
Physical Component Score (PCS) (Ref: Lowest 15th percentile)				
Middle 70th percentile	.82 (0.67–1.00)	—	—	.95 (0.77–1.18)
Highest 15th percentile	**.73 (0.55–0.98)**	—	—	.89 (0.66–1.20)
Ever classified as obese (Ref: No)				
Yes	**.72 (0.61–0.86)**	—	—	**.67 (0.56–0.80)**
Ever smoker (Ref: No)				
Yes	**1.63 (1.39–1.90)**	—	—	**1.38 (1.16–1.64)**
Ever long sleep duration (9+ hours) (Ref: No)				
Yes	**1.25 (1.01–1.54)**	—	—	1.07 (0.86–1.33)
Ever screened for probable PTSD (PCL-C) (Ref: No)				
Yes	1.15 (0.92–1.42)	—	—	1.04 (0.79–1.38)
Ever screened for probable depression (PHQ-8) (Ref: No)				
Yes	1.15 (0.90–1.48)	—	—	.98 (0.71–1.35)

Note: Bolded values indicate significant associations.
Model 1 includes sociodemographic factors: sex, race, ethnicity, education, marital status, enrollment panel.
Model 2 includes sociodemographic and military factors: sex, race, ethnicity, education, marital status, enrollment panel, service component, service branch, military rank, military occupation, deployment/combat experience.
Model 3 includes sociodemographic, military and health-related factors: sex, race, ethnicity, education, marital status, enrollment panel, service component, service branch, military rank, military occupation, deployment/combat experience, risky drinking, life stressors, PCS, obesity, smoking status, sleep duration, PTSD, depression.

Table 3. Unadjusted and adjusted effect estimates for early cancer mortality.

	Unadjusted Models (n = 194,689, 151 deaths) Unadjusted HR (95% CI)	Model 1 (n = 194,678, 151 deaths) Adjusted HR (95% CI)	Model 2 (n = 193,337, 150 deaths) Adjusted HR (95% CI)	Model 3 (n = 183,622, 141 deaths) Adjusted HR (95% CI)
Sex (Ref: Female)				
Male	**63 (0.46–0.87)**	**.61 (0.44–0.86)**	**.66 (0.45–0.95)**	.79 (0.53–1.17)
Race and ethnicity (Ref: White, Non-Hispanic)				
Asian/Pacific Islander/American Indian/ Multiracial	1.05 (0.57–1.96)	1.03 (0.55–1.92)	1.03 (0.55–1.93)	1.07 (0.57–2.00)
Black, Non-Hispanic	1.08 (0.68–1.71)	.91 (0.57–1.45)	.94 (0.59–1.51)	.82 (0.49–1.38)
Hispanic	.77 (0.39–1.52)	.73 (0.37–1.44)	.75 (0.38–1.49)	.80 (0.40–1.60)
Marital status (Ref: Married)				
Single, Never Married	**1.62 (1.12–2.36)**	**1.48 (1.01–2.17)**	**1.52 (1.03–2.23)**	**1.66 (1.11–2.48)**
Separated, divorced, or widowed	1.53 (0.96–2.42)	1.30 (0.81–2.08)	1.28 (0.80–2.07)	1.18 (0.70–1.99)
Highest achieved education level (Ref: Associate's or Bachelor's degree)				
High School Diploma or less	**2.00 (1.19–3.37)**	**2.18 (1.29–3.69)**	**2.12 (1.24–3.66)**	**1.93 (1.09–3.43)**
Some College	**1.66 (1.13–2.43)**	**1.73 (1.18–2.54)**	**1.71 (1.15–2.55)**	**1.67 (1.11–2.52)**
Master's degree or higher	.85 (0.50–1.42)	.83 (0.50–1.40)	.74 (0.42–1.33)	.70 (0.38–1.29)
Enrollment panel (Ref: Panel 1)				
Panel 2	.95 (0.58–1.55)	.92 (0.56–1.50)	1.02 (0.62–1.68)	.92 (0.54–1.54)
Panel 3	1.04 (0.62–1.72)	1.07 (0.64–1.77)	1.21 (0.72–2.01)	1.13 (0.67–1.91)
Panel 4	**.44 (0.22–0.91)**	.52 (0.26–1.07)	.60 (0.28–1.27)	.45 (0.20–1.05)
Service component (Ref: Reserve/National Guard)				
Active Duty	1.09 (0.78–1.53)	—	1.18 (0.82–1.69)	1.23 (0.84–1.79)
Service branch (Ref: Air Force)				
Army	.87 (0.59–1.29)	—	.84 (0.56–1.26)	.95 (0.61–1.46)
Marine Corps	1.23 (0.78–1.92)	—	1.02 (0.65–1.62)	1.19 (0.73–1.92)
Navy/Coast Guard	1.16 (0.61–2.22)	—	.94 (0.47–1.87)	1.09 (0.54–2.20)
Military rank (Ref: Officer)				
Enlisted	1.34 (0.86–2.08)	—	.78 (0.44–1.38)	.84 (0.46–1.54)
Military occupation (Ref: Combat Specialist)				
Functional Support	1.23 (0.72–2.12)	—	.96 (0.54–1.71)	.93 (0.51–1.68)
Health Care	1.19 (0.64–2.20)	—	.94 (0.49–1.81)	1.04 (0.54–2.01)
Other	1.22 (0.77–1.94)	—	1.04 (0.64–1.68)	1.03 (0.63–1.68)
Deployment/Combat (Ref: Deployed, No Combat)				
Deployed, with Combat	.88 (0.50–1.52)	—	.95 (0.54–1.68)	.93 (0.52–1.67)
Not Deployed	**2.03 (1.24–3.34)**	—	**1.93 (1.16–3.21)**	**1.80 (1.06–3.04)**
Ever risky drinking (Ref: No)				
Yes	**.69 (0.50–0.96)**	—	—	.73 (0.51–1.05)
Ever life stressors (Ref: No Life Stressors)				
1 Life Stressors	.90 (0.59–1.38)	—	—	.95 (0.61–1.49)
2 or more Life Stressors	1.20 (0.83–1.74)	—	—	1.23 (0.79–1.93)
Physical Component Score (PCS) (Ref: Lowest 15th percentile)				
Middle 70th percentile	.70 (0.47–1.06)	—	—	.75 (0.49–1.16)
Highest 15th percentile	**.48 (0.26–0.89)**	—	—	**.51 (0.27–0.98)**
Ever classified as obese (Ref: No)				
Yes	**.54 (0.36–0.82)**	—	—	**.49 (0.31–0.77)**
Ever smoker (Ref: No)				
Yes	1.06 (0.77–1.46)	—	—	.93 (0.65–1.33)
Ever long sleep duration (9+ hours) (Ref: No)				
Yes	1.45 (0.94–2.24)	—	—	1.20 (0.75–1.93)
Ever screened for probable PTSD (PCL-C) (Ref: No)				
Yes	.93 (0.59–1.46)	—	—	1.00 (0.55–1.82)
Ever screened for probable depression (PHQ-8) (Ref: No)				
Yes	.86 (0.50–1.46)	—	—	.82 (0.42–1.63)

Note: Bolded values indicate significant associations.
Model 1 includes sociodemographic factors: sex, race, ethnicity, education, marital status, enrollment panel.
Model 2 includes sociodemographic and military factors: sex, race, ethnicity, education, marital status, enrollment panel, service component, service branch, military rank, military occupation, deployment/combat experience.
Model 3 includes sociodemographic, military and health-related factors: sex, race, ethnicity, education, marital status, enrollment panel, service component, service branch, military rank, military occupation, deployment/combat experience, risky drinking, life stressors, PCS, obesity, smoking status, sleep duration, PTSD, depression.

being married. Individuals who had lower education levels showed greater risk of early cancer mortality compared with those with an associate's or bachelor's degree. Sex and enrollment panel were associated with early cancer mortality in unadjusted models but were no longer significant in the final adjusted model. Race and ethnicity were not significantly associated with early cancer mortality in unadjusted or adjusted models.

For military characteristics, non-deployed individuals had approximately 80% greater early cancer mortality risk than those deployed with no combat. No difference was found between those deployed with combat and those deployed without combat. Service component, service branch, rank, and military occupation were not associated with early cancer mortality in unadjusted or adjusted models.

For health-related characteristics, individuals with obesity showed lower early cancer mortality risk compared with those never classified as obese. Individuals in the highest 15th percentile of the PCS had lower early cancer mortality risk compared with those in the lowest 15th percentile. Risky drinking was associated with early cancer mortality in unadjusted models but was no longer significant in the final adjusted model. Life stressors, smoking status, long sleep duration, probable PTSD, and probable depression were not significantly associated with early cancer mortality risk in unadjusted or adjusted models.

Lung cancer mortality

Among 661 cancer-related deaths, 121 identified lung cancer as the cause of death. Unadjusted and adjusted HRs and 95% CIs for lung cancer mortality are reported in **Table 4**.

For demographic characteristics, non-Hispanic Black individuals had almost twofold greater lung cancer mortality risk compared with non-Hispanic White individuals. Being single was associated with greater lung cancer mortality risk compared with those who reported being married. Individuals with a high school degree or less had greater lung cancer mortality risk compared with those with an associate's or bachelor's degree. Sex and enrollment panel were not associated with lung cancer mortality in unadjusted or adjusted models.

For military characteristics, enlisted individuals showed almost threefold greater lung cancer mortality risk than officers. Although deployment was associated with lung cancer mortality in unadjusted and demographically adjusted models, this effect was no longer significant after adjusting for health-related characteristics. Service component, service branch, and military occupation were not associated with lung cancer mortality in unadjusted or adjusted models.

For health-related characteristics, individuals who experienced 1 or 2+ life stressors had greater lung cancer mortality risk than those who reported none. Individuals with obesity had lower lung cancer mortality risk compared with those never classified as obese. Individuals ever identified as smokers had more than 4 times the likelihood of lung cancer mortality than nonsmokers. Probable depression and PCS were associated with lung cancer mortality risk in unadjusted models, but not adjusted models. Risky drinking, long sleep duration and probable PTSD were not significantly associated with lung cancer mortality in unadjusted or adjusted models.

Sensitivity analyses

To test the robustness of our findings, overall cancer mortality, early cancer mortality, and lung cancer mortality were reanalyzed using Fine-Gray subdistribution hazard models rather than cause-specific Cox proportional hazard models to handle competing risk of other non-cancer deaths. The pattern of findings was consistent with those reported in our primary models. Multiple sensitivity analyses were conducted (i) adjusting for physical and sedentary activity, (ii) using time-on-study rather than chronological age as the time scale, (iii) examining cumulative time spent on deployments, (iv) examining BMI-cancer mortality associations among participants who identified as nonsmokers, (v) examining more detailed information regarding smoking status at study entry (i.e., former, current, and nonsmokers) and (vi) examining the effect of military rank on lung cancer mortality using a more fine-grained assessment of rank (i.e., junior enlisted, noncommissioned officer, senior noncommissioned officer, junior commissioned or warrant officer, senior commissioned or warrant officer). Findings from sensitivity analyses are reported in Supplemental Materials. In brief, the pattern of findings from the sensitivity analyses were consistent with the results reported in our primary models.

Discussion

The aim of the current study was to explore the association between military service characteristics and cancer mortality in a large, population-based sample of OIF/OEF service members and veterans. We found that non-deployed individuals had greater risk of overall cancer mortality and early cancer mortality compared with those who were deployed with no combat. In addition, no difference was found between those who deployed with or without combat, suggesting that the lower of risk of cancer mortality associated with deployment was present regardless of combat experiences. This finding is consistent with the healthy soldier effect where military populations are found to be healthier than the general population (34, 35), which may be partially attributable to the initial barriers to entry into military service (i.e., physical screenings), physical health requirements necessary to remain in military service and increased access to housing and healthcare benefits received during military service. Further, military service members may engage in cancer screenings more frequently because of the universal availability of healthcare provided by the military healthcare system. This may potentially lead to earlier detection of cancer and therefore, reduce risk of cancer-related deaths within the active duty military population. Our findings specifically support the healthy deployer effect and are consistent with prior research (36) concluding that those who deployed may be healthier than individuals in the service who did not deploy (34, 37, 38). Supplementary Table S1 which compared health and lifestyle characteristics by deployment and combat experience is consistent with this notion and showed that deployers compared with non-deployers are more physically active and have a lower prevalence of asthma, coronary heart disease, diabetes, and hypertension.

In addition, military rank was associated with overall cancer mortality in unadjusted models only and with lung cancer mortality in both adjusted and unadjusted models. Consistent with prior research linking lower military rank and worse health outcomes (39–41), enlisted individuals had elevated risk of lung cancer mortality compared with officers. This may be due in part to greater frequency of cigarette smoking, an established risk factor for lung cancer. For instance, in a longitudinal study, noncommissioned officers were less likely to start smoking and were more likely to quit smoking compared with those in the junior enlisted rank (42). However, even after adjustment for smoking in the current study, the elevated risk death due to lung cancer among enlisted personnel remained, suggesting other occupational risk factors may exist. Individuals in enlisted ranks may perform tasks that more frequently expose them to occupational hazards (e.g., carbon monoxide, respiratory carcinogens, and other toxicants) compared with

Table 4. Unadjusted and adjusted effect estimates for lung cancer mortality.

	Unadjusted Models (n = 194,689, 121 deaths) Unadjusted HR (95% CI)	Model 1 (n = 194,678, 121 deaths) Adjusted HR (95% CI)	Model 2 (n = 193,337, 121 deaths) Adjusted HR (95% CI)	Model 3 (n = 183,622, 117 deaths) Adjusted HR (95% CI)
Sex (Ref: Female)				
Male	.81 (0.54–1.21)	.74 (0.48–1.16)	.73 (0.46–1.17)	.84 (0.51–1.36)
Race and ethnicity (Ref: White, Non-Hispanic)				
Asian/Pacific Islander/American Indian/Multiracial	1.52 (0.74–3.14)	1.54 (0.74–3.18)	1.46 (0.70–3.02)	1.42 (0.65–3.08)
Black, Non-Hispanic	**1.83 (1.16, 2.89)**	**1.63 (1.02–2.60)**	1.44 (0.89–2.32)	**1.87 (1.15–3.03)**
Hispanic	.83 (0.34–2.05)	.76 (0.31–1.87)	.69 (0.28–1.71)	.83 (0.33–2.05)
Marital status (Ref: Married)				
Single, never married	1.72 (0.97–3.07)	1.56 (0.86–2.84)	1.54 (0.84–2.80)	**1.87 (1.02–3.43)**
Separated, divorced, or widowed	1.24 (0.77–1.98)	1.04 (0.64–1.70)	1.00 (0.61–1.62)	.85 (0.52–1.40)
Highest achieved education level (Ref: associate's or bachelor's degree)				
High school diploma or less	**2.99 (1.79–5.00)**	**3.19 (1.90–5.36)**	**2.74 (1.60–4.67)**	**2.54 (1.46–4.40)**
Some college	**1.67 (1.09–2.57)**	**1.73 (1.12–2.66)**	1.50 (0.97–2.33)	1.39 (0.89–2.17)
Master's degree or higher	**.43 (0.24–0.79)**	**.43 (0.24–0.78)**	.72 (0.37–1.40)	.82 (0.42–1.59)
Enrollment panel (Ref: Panel 1)				
Panel 2	2.02 (0.84–4.85)	2.12 (0.88–5.12)	2.45 (1.00–6.05)	2.18 (0.90–5.31)
Panel 3	.44 (0.06–3.52)	.50 (0.06–4.04)	.62 (0.08–5.04)	.58 (0.07–4.70)
Panel 4	.49 (0.06–3.77)	.61 (0.08–4.73)	.76 (0.10–5.91)	.74 (0.09–5.81)
Service component (Ref: Reserve/National Guard)				
Active Duty	.90 (0.59–1.37)	—	1.28 (0.80–2.02)	1.15 (0.72–1.84)
Service branch (Ref: Air Force)				
Army	1.21 (0.80–1.82)	—	1.11 (0.72–1.69)	.99 (0.64–1.54)
Marine Corps	1.09 (0.63–1.88)	—	.94 (0.53–1.66)	.98 (0.55–1.75)
Navy/Coast Guard	.36 (0.05–2.63)	—	.34 (0.05–2.52)	.33 (0.04–2.47)
Military rank (Ref: Officer)				
Enlisted	**4.87 (2.68–8.85)**	—	**3.32 (1.60–6.89)**	**2.65 (1.27–5.53)**
Military occupation (Ref: Combat Specialist)				
Functional Support	1.20 (0.66–2.16)	—	.83 (0.45–1.54)	.81 (0.43–1.51)
Health Care	.88 (0.43–1.82)	—	1.10 (0.51–2.36)	1.15 (0.53–2.49)
Other	1.39 (0.81–2.38)	—	1.04 (0.60–1.80)	1.02 (0.59–1.77)
Deployment/Combat (Ref: Deployed, No Combat)				
Deployed, with Combat	1.65 (0.62–4.35)	—	1.92 (0.72–5.09)	1.56 (0.58–4.19)
Not Deployed	**2.75 (1.11–6.81)**	—	**2.90 (1.16–7.24)**	2.46 (0.98–6.16)
Ever risky drinking (Ref: No)				
Yes	1.15 (0.80–1.65)	—	—	.91 (0.62–1.33)
Ever life stressors (Ref: No Life Stressors)				
1 Life Stressor	**2.12 (1.25–3.60)**	—	—	**1.82 (1.06–3.14)**
2 or more Life Stressors	**2.54 (1.54–4.19)**	—	—	**1.86 (1.08–3.21)**
Physical Component Score (PCS) (Ref: Lowest 15th percentile)				
Middle 70th percentile	**.58 (0.38–0.89)**	—	—	.81 (0.51–1.26)
Highest 15th percentile	.56 (0.29–1.07)	—	—	.89 (0.45–1.75)
Ever classified as obese (Ref: No)				
Yes	**.44 (0.28–0.69)**	—	—	**.36 (0.22–0.57)**
Ever smoker (Ref: No)				
Yes	**5.67 (3.43–9.38)**	—	—	**4.38 (2.60–7.38)**
Ever long sleep duration (9+ hours) (Ref: No)				
Yes	1.18 (0.73–1.92)	—	—	.87 (0.53–1.44)
Ever screened for probable PTSD (PCL-C) (Ref: No)				
Yes	1.57 (0.99–2.49)	—	—	.89 (0.48–1.66)
Ever screened for probable depression (PHQ-8) (Ref: No)				
Yes	**2.18 (1.36–3.49)**	—	—	1.58 (0.83–3.02)

Note: Bolded values indicate significant associations.
Model 1 includes sociodemographic factors: sex, race, ethnicity, education, marital status, enrollment panel.
Model 2 includes sociodemographic and military factors: sex, race, ethnicity, education, marital status, enrollment panel, service component, service branch, military rank, military occupation, deployment/combat experience.
Model 3 includes sociodemographic, military and health-related factors: sex, race, ethnicity, education, marital status, enrollment panel, service component, service branch, military rank, military occupation, deployment/combat experience, risky drinking, life stressors, PCS, obesity, smoking status, sleep duration, PTSD, depression.

officers (43, 44), which may in turn, lead to poorer respiratory health (e.g., sarcoidosis and asthma incidence; ref. 45).

Other military characteristics, specifically military occupation, service branch, and service component, were not associated with cancer mortality in the current study. To our knowledge, no prior work has systematically examined these military characteristics and cancer mortality among OIF/OEF service members and veterans. As this study assessed military characteristics and cancer mortality more broadly, future research is necessary to understand the potential unique exposures associated with specific deployment locations related to service branch and/or occupation.

The current study also found that several sociodemographic and health-related characteristics were associated with cancer mortality. Individuals enrolled in Panel 4 had reduced risk of overall cancer mortality than Panel 1, which may be due to Panel 4 being a younger cohort than Panel 1. Indeed, the mean age at death or end of the follow-up period for Panel 4 (34.4 years, SD = 4.9 years) was younger than Panel 1 (51.7 years, SD = 9.1 years). Consistent with prior work, a history of smoking (46, 47) and experiencing life stressors were associated with increased risk of overall and lung cancer mortality (48). Sensitivity analyses additionally found that while both current and former smokers had greater overall and lung cancer mortality risk than nonsmokers, risk appeared to be highest among current smokers (see Supplemental Materials). Several health-related factors, such life stressors, sleep, or history of smoking, were not associated with early cancer mortality, consistent with the notion that cancers experienced in early adulthood may be distinct from cancer developed in later life (17, 49). In addition, the observed findings were consistent with the obesity paradox such that individuals who ever had a BMI ≥ 30 had lower overall, early, and lung cancer mortality risk (50, 51). This finding may be partially due to the use of self-reported BMI as the primary index for body size, which does not differentiate between adipose tissue and muscle mass (51, 52). Although prior meta-analytic research has linked depression and cancer mortality (48, 53, 54), no association between probable depression and cancer mortality was found in the current study. Prior meta-analytic work noted that the association between depression and cancer mortality was stronger in studies with shorter time intervals between depression diagnosis and cancer mortality (53) and therefore, depression may be a prodrome of cancer mortality rather than a risk factor. In addition, no association was found between probable PTSD and cancer mortality, consistent with some research finding no link between PTSD and cancer mortality (55).

Limitations and future directions

The current study has several strengths, such as the use of a large population-based sample of U.S. service members and veterans, a long follow-up period, and the examination of multiple, distinct military characteristics. Despite these strengths, there are several notable limitations, such as the lack of assessment of specific occupational hazards and environmental exposures. Future research is necessary using objective records of deployment locations, and/or occupational and environmental exposures incurred during military service, such as the Individual Longitudinal Exposure Record, to better understand why certain military subpopulations may experience greater risk of cancer mortality and inform the development of preventive interventions and practices. In addition, another limitation is the current unavailability of registry data for more detailed ascertainment of stage at diagnosis and cancer histology. Future research should incorporate histological type and molecular subtype as well as access to and/or utilization of cancer screenings and/or treatments within the military to extend these findings. Further, health-related characteristics used in the current study were largely self-reported and additional work with more objective indexes of health and health-related behaviors is necessary to corroborate these findings. Future research in the current study population should examine whether this pattern of findings we observed is consistent across other military era cohorts such as Gulf War or Vietnam veterans. Finally, the Millennium Cohort Study is a relatively young cohort (e.g., predominantly younger, and middle-aged adults) and therefore, this may have contributed to the small number of cancer-related deaths in the current study. The small number of cancer-related deaths limited our ability to examine associations between risk factors and specific cancer sites that had relatively few cases. Future research should extend these findings once a majority of the Millennium Cohort Study participants reach older adulthood.

Conclusion

The healthy deployer effect was consistently found for overall and early cancer mortality among OEF/OIF service members and veterans. Enlisted military rank also was associated with a higher risk for lung cancer mortality. These findings, as well as the robust association between higher educational attainment and lower risk of overall, early, and lung cancer mortality, highlights the importance of considering modifiable socioeconomic factors that affect risk of cancer mortality in military service members and veterans. Other military characteristics which have not been systematically examined in prior work among OIF/OEF service members and veterans, such as service component, service branch, and occupation, were not linked to overall, early, and lung cancer mortality. As this study assessed military characteristics and cancer mortality more broadly, future research is necessary to understand the potential unique exposures that may be associated with specific military characteristics, and that may increase cancer mortality risk for certain military subpopulations.

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Disclaimer

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Authors' Contributions

N. Sharifian: Conceptualization, formal analysis, methodology, writing–original draft, writing–review and editing. **F.R. Carey:** Formal analysis, investigation, writing–review and editing. **J.S. Seay:** Investigation, writing–review and editing. **S.F. Castañeda:** Investigation, writing–review and editing.

E.J. Boyko: Investigation, writing–review and editing. **R.P. Rull:** Resources, supervision, investigation, writing–review and editing.

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Note

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