Research Square

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Dose-Response Associations Between Physical Activity and All- Cause Mortality in are consistent across Veteran and Non-Veteran Populations: A Nationally Representative Cohort Study

Adam Potter

adam.w.potter.civ@health.mil

US Army Research Institute of Environmental Medicine

William Tharion

US Army Research Institute of Environmental Medicine

David Looney

CoachMePlus

Caroline Murphy

US Army Research Institute of Environmental Medicine

Karl Friedl

US Army Research Institute of Environmental Medicine

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Abstract

Background: Physical activity is a key modifiable determinant of mortality risk, yet it remains unclear whether its association with all-cause mortality differs across populations with distinct occupational and life-course exposures, such as U.S. military veterans. Understanding the generalizability of physical activity–mortality relationships is important for informing population-wide prevention strategies.

Methods: We analyzed data from the National Health and Nutrition Examination Survey (NHANES) 2007–2018 linked to mortality outcomes through December 31, 2019. Adults aged ≥20 years with complete data on physical activity, veteran status, and covariates were included (n = 13,260). Weekly moderate-to-vigorous physical activity (MVPA) was calculated using guideline-equivalent minutes. Survey-weighted Cox proportional hazards models estimated hazard ratios (HRs) for all-cause mortality across MVPA categories. Nonlinear dose–response relationships were assessed using restricted cubic splines. Effect modification by veteran status was evaluated using interaction terms.

Results: Over a median follow-up of 73 months, 1,703 deaths occurred. Compared with inactive individuals, insufficiently active participants had a lower mortality risk (HR 0.81, 95% CI 0.68–0.96), and those meeting physical activity guidelines (≥150 min/week) had substantially lower risk (HR 0.62, 95% CI 0.51–0.75). Dose–response analyses demonstrated the greatest reduction in mortality risk when increasing MVPA from 0 to approximately 300 minutes/week, with diminishing returns at higher volumes. Although veterans had higher absolute mortality rates, the shape and magnitude of the association between MVPA and mortality were similar across groups, with no significant interaction by veteran status (P = 0.21).

Conclusions: Higher levels of physical activity are strongly associated with lower all-cause mortality in U.S. adults, with consistent dose–response patterns across veteran and non-veteran populations. These findings support the broad applicability of current physical activity recommendations and highlight the potential population-level benefits of increasing physical activity, particularly among inactive individuals.

Background

Physical inactivity is a leading modifiable risk factor for premature mortality globally. While physical activity (PA) is a key health behavior, its primary benefit is the improvement of cardiorespiratory fitness (CRF), a physiological attribute that is an even stronger and more robust predictor of all-cause mortality (1, 2). Large prospective cohort studies and pooled analyses consistently demonstrate an inverse, non-linear dose-response relationship between leisure-time moderate-to-vigorous physical activity (MVPA) and all-cause mortality, with the most substantial survival benefits occurring when sedentary individuals begin to incorporate even modest levels of activity (3–6).

Current U.S. guidelines recommend at least 150 minutes per week of moderate-intensity activity, 75 minutes of vigorous-intensity activity, or an equivalent combination (7). However, recent evidence has revealed a "physical activity health paradox," suggesting that not all physical activity confers the same

health benefits (8–10). While high levels of leisure-time physical activity (LTPA) are protective, high levels of occupational physical activity (OPA) have been associated with a neutral or even increased risk of all-cause mortality, particularly in men (9, 11). This paradox highlights that the context, intensity, and duration of physical activity are critical determinants of its health impact (10).

Military service represents a unique life-course exposure characterized by structured physical training, which often includes high levels of OPA, alongside other occupational demands and environmental stressors. While this may foster an initial "healthy soldier effect" (12, 13), this advantage often erodes post-service, with veterans exhibiting higher rates of smoking and obesity (14, 15), and often a decline in physical activity after transitioning to civilian life (16). Despite extensive literature linking LTPA with mortality in the general population, fewer studies have examined whether the strength or shape of this association differs between veterans and non-veterans, a population for whom the physical activity paradox may be particularly relevant. Understanding potential heterogeneity is essential for tailoring preventive interventions and contextualizing public health guidance for former military personnel.

Therefore, we examined the association between leisure-time MVPA and all-cause mortality in pooled data from the National Health and Nutrition Examination Survey (NHANES) 2007–2018 with linked mortality follow-up, and tested whether veteran status modifies this relationship. We hypothesized that higher MVPA would be associated with lower mortality risk and that the relative association would be similar between veterans and non-veterans.

Methods

Study Population

We analyzed data from six NHANES cycles (2007–2008 through 2017–2018). NHANES uses a complex, multistage probability sampling design to represent the civilian, noninstitutionalized U.S. population. Mortality status was determined through linked data with the National Death Index through December 31, 2019. Of the total 58,069 adults aged ≥ 20 years in the 2007–2018 cycles, we excluded participants with missing data for physical activity (n = 7,413), veteran status as N/A (n = 11,258), key covariates (n = 1,483), or mortality follow-up (n = 24,655), resulting in a final analytic cohort of 13,260, including 1,238 veterans.

Participants aged ≥ 20 years with valid mortality linkage, available physical activity data, veteran status information, and complete covariates were included. Survey weights, clustering, and stratification variables were applied in all analyses in accordance with NHANES analytic guidelines.

The NHANES protocol was approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board, and all participants provided written informed consent. Additionally, the authors' institutional review board determined this project, involving the secondary analysis of de-identified, publicly available data, to be exempt from its review and not classified as human subjects research, as confirmed in determination letter #26-06-R.

Physical Activity Assessment

Physical activity was assessed using the NHANES Physical Activity Questionnaire, which quantifies the frequency and duration of activities in leisure, transportation, and work domains. To align with the 2018 Physical Activity Guidelines for Americans[7], we calculated total weekly minutes of moderate-to-vigorous physical activity (MVPA). Following guideline recommendations, which consider vigorous-intensity activity to confer approximately double the benefit of moderate-intensity activity per unit of time, vigorous-intensity minutes were multiplied by two before being summed with moderate-intensity minutes (Total MVPA = moderate minutes + [2 × vigorous minutes]). For categorical analyses, participants were classified as: 1) Inactive (0 MVPA minutes/week), 2) Insufficiently Active (1–149 MVPA minutes/week), or 3) Active (≥ 150 MVPA minutes/week). For dose-response modeling, continuous MVPA was winsorized at the 99th percentile to mitigate the influence of extreme outliers.

Veteran Status

Veteran status was obtained from the Demographics questionnaire (variable DMQMILIT). Participants who responded "Yes" to the question, "Have you ever served on active duty in the U.S. Armed Forces?" were classified as veterans. All other participants were classified as non-veterans for the purpose of this analysis.

Mortality Outcome

The primary outcome was all-cause mortality, which was obtained via linked data from the public-access National Death Index (NDI) mortality file with follow-up data through December 31, 2019. Person-time for each participant was calculated from the date of the mobile examination center (MEC) interview until the date of death or the end of the follow-up period (December 31, 2019), whichever occurred first.

Covariates

Based on prior literature and their availability in NHANES, we selected several covariates *a priori* as potential confounders. Multivariable models were adjusted for age (in years, continuous), sex (male/female), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, other), educational attainment (< high school, high school graduate, some college, college graduate or higher), the ratio of family income to the poverty line (continuous), smoking status (never, former, current), and alcohol consumption (never, moderate, heavy). All covariates were assessed at baseline.

Statistical Analysis

All analyses were performed using R (Version 4.4.1; R Foundation for Statistical Computing; Vienna, Austria), accounting for the complex survey design. Survey-weighted Cox proportional hazards

regression estimated hazard ratios (HRs) and 95% confidence intervals (CIs). NHANES survey weights were pooled across cycles in accordance with National Center for Health Statistics guidelines, and all analyses accounted for the complex survey design, including clustering and stratification. Proportional hazards assumptions were evaluated using time-dependent diagnostics. Restricted cubic splines modeled nonlinear dose–response relationships between continuous MVPA and mortality. Interaction between continuous MVPA spline terms and veteran status was assessed using a Wald test. Kaplan–Meier curves illustrated unadjusted survival by MVPA category. All analyses incorporated the NHANES complex survey design. We used 4 knots for the restricted cubic splines, placed at the 5th, 35th, 65th, and 95th percentiles of the MVPA distribution. A two-sided P-value < 0.05 was considered statistically significant. To reduce the potential for reverse causation, a sensitivity analysis was performed excluding deaths occurring within the first 24 months of follow-up. Results were compared with the primary analysis to assess robustness.

Results

Study Population

The final analytic cohort consisted of 13,260 adults, representing a weighted population of approximately 214 million noninstitutionalized U.S. adults. Over a median follow-up of 73 months (81,645 person-years), 1,703 deaths occurred.

Baseline characteristics of the study population, stratified by veteran status, are presented in Table 1. Compared with non-veterans, veterans were substantially older (mean age, 61.8 vs. 45.1 years), more likely to be male (90.9% vs. 47.6%), and had a higher unadjusted mortality rate (16.8% vs. 11.9%). The distribution of moderate-to-vigorous physical activity (MVPA) was comparable between the two groups, with a median of 130 minutes/week for veterans and 120 minutes/week for non-veterans (Fig. 1).

Table 1
Weighted Baseline Characteristics of U.S. Adults by Veteran Status, NHANES 2007–2018

Characteristic	Non-Veteran (n = 12,022)	Veteran (n = 1,238)
Age, mean (SE), years	45.1 (0.4)	61.8 (0.8)
Male, %	47.6	90.9
Non-Hispanic White, %	63.4	74.8
Non-Hispanic Black, %	12.2	12.5
Hispanic, %	16.1	7.3
College education or higher, %	32.8	29.4
Income-to-poverty ratio, mean (SE)	2.6 (0.1)	2.4 (0.1)
Current smoker, %	20.3	18.7
Alcohol use (≥ 1 drink/week), %	56.9	61.4
MVPA, median (IQR), min/week	120 (0–240)	130 (0–240)
Meets MVPA guidelines (≥ 150 min/week), %	48.7	51.2
All-cause mortality during follow-up, %	11.9	16.8

Abbreviations: IQR, interquartile range; MVPA, moderate-to-vigorous physical activity; SE, standard error.

[Insert Table 1 **here]**

[Insert Fig. 1 **here]**

Physical Activity Categories and Mortality

Table 2 shows the association between physical activity categories and all-cause mortality after multivariable adjustment. Compared with inactive individuals, engaging in any activity was associated with lower mortality risk. The association was dose-dependent: insufficiently active participants had an adjusted hazard ratio (HR) of 0.81 (95% Confidence Interval [CI]: 0.68, 0.96), while those meeting or exceeding activity guidelines had an even lower risk (HR 0.62, 95% CI: 0.51, 0.75). Unadjusted Kaplan-Meier survival curves showed a clear, graded separation in survival probability across the three activity categories (Fig. 2)

Table 2
Adjusted Hazard Ratios for All-Cause Mortality by Physical Activity Category, NHANES 2007–2018. Reference group: Inactive (0 minutes/week)

MVPA Category	Hazard Ratio	95% Confidence Interval	P value
Inactive	1.00	Reference	—
1–149 min/week	0.81	0.68–0.96	0.02
≥ 150 min/week	0.62	0.51–0.75	< 0.001

Note: Adjusted for age, sex, race/ethnicity, education, income-to-poverty ratio, smoking status, and alcohol use.

[Insert Table 2 **here]**

[Insert Fig. 2 **here]**

Weighted Mortality by Guideline and Veteran Status

The nonlinear dose-response relationship between continuous MVPA and mortality risk, modeled using restricted cubic splines, is visualized in Fig. 3. The analysis revealed a steep inverse association, with the largest mortality reduction observed when moving from 0 to approximately 300 MVPA minutes/week, after which the association attenuated.

Although veterans had higher absolute mortality rates within each physical activity category (Table 3 and Fig. 2), the relative association between MVPA and mortality was visually similar for both veterans and non-veterans, as shown by the nearly parallel adjusted hazard curves in Fig. 4. A formal test for interaction confirmed this observation, showing no statistically significant interaction between MVPA (as a continuous spline term) and veteran status on the risk of all-cause mortality (Wald $\chi^2 = 4.53$, P for interaction = 0.21).

Table 3
Weighted Mortality Percentage by Physical Activity Guideline Category and Veteran Status

Veteran Status	MVPA Category	Weighted Mortality %	95% CI
Non-Veteran	**Inactive**	16.2	14.4–18.1
Non-Veteran	**1–149 min/week**	12.8	11.0–14.7
Non-Veteran	**≥ 150 min/week**	9.6	8.2–11.2
Veteran	**Inactive**	22.4	18.1–27.3
Veteran	**1–149 min/week**	18.7	14.8–23.4
Veteran	**≥ 150 min/week**	14.1	11.0–17.9

Note: Survey-weighted estimates incorporating NHANES complex design.

[Insert Table 3 **here]**

[Insert Fig. 3 **here]**

Association of Physical Activity by Veteran Status

To assess whether veteran status modified the association between physical activity and mortality, we first stratified the adjusted dose-response curves (Fig. 4). The shapes of the curves were highly similar for veterans and non-veterans, indicating that the magnitude of the association was comparable in both populations. A formal test for interaction affirmed this finding, revealing no statistically significant effect modification by veteran status (Wald $\chi^2 = 4.53$, df = 3, P = 0.21). This indicates that while baseline mortality risk differs, the protective association of physical activity is of a similar magnitude in both veterans and non-veterans.

[Insert Fig. 4 **here]**

In sensitivity analyses excluding deaths within the first 24 months of follow-up, the associations between MVPA and all-cause mortality were materially unchanged, indicating that reverse causation is unlikely to explain the observed findings.

Discussion

In this large, nationally representative cohort of U.S. adults, higher levels of leisure-time MVPA were strongly and inversely associated with all-cause mortality. This association was nonlinear, with the largest risk reductions observed when moving from inactivity to moderate levels of activity, and diminishing returns at higher volumes. Importantly, this protective association was consistent in both magnitude and shape for veterans and non-veterans, with no evidence of a statistically significant interaction.

Our findings on the dose-response relationship align with prior large-scale prospective analyses, which have consistently demonstrated a curvilinear association between LTPA and mortality (3, 17). The observation that even activity levels below the recommended 150 minutes/week are associated with lower mortality risk reinforces a key public health message: for sedentary individuals, modest increases in regular physical activity are associated with meaningful long-term benefit. (6, 17). It is important, however, to distinguish between habitual physical activity volume and the acute physiological stress of isolated, unaccustomed bouts of high-intensity exertion. Prior studies have shown that vigorous exertion can transiently increase the risk of acute cardiovascular events in susceptible individuals, particularly when the activity is abrupt and not part of a regular training pattern. NHANES does not capture activity context, conditioning status, or bout-level characteristics (e.g., episodic heavy exertion such as snow shoveling), and our analyses therefore reflect the net association of reported habitual weekly activity

volume with long-term mortality risk rather than the instantaneous risk associated with specific exertional episodes.

Importantly, regular physical activity is known to reduce baseline cardiovascular risk and attenuate the relative triggering effect of acute exertion. Thus, while isolated high-intensity tasks performed without conditioning may transiently elevate risk, habitual moderate-to-vigorous activity is consistently associated with lower long-term mortality, as observed in the present study.

The Physical Activity Health Paradox and Cardiorespiratory Fitness

Our finding of a consistent protective effect of LTPA in both veterans and non-veterans is particularly noteworthy in the context of the "physical activity health paradox." Recent meta-analyses have shown that high levels of OPA, common in many military roles, do not confer the same mortality benefits as LTPA and may even increase mortality risk in men (9, 11). This paradox is thought to arise because OPA often involves prolonged, low-intensity exertion with insufficient recovery, which can lead to sustained physiological strain and chronic inflammation without improving cardiorespiratory fitness (CRF) (10). However, structured leisure-time training can effectively build CRF even in populations with high OPA. Research on U.S. Marines has shown that both aerobic-only and combined aerobic-resistance training are associated with superior aerobic fitness, suggesting that the type and structure of LTPA are critical for improving health outcomes (18). Furthermore, the overall activity profile of a physically demanding occupation may still confer net health benefits. For instance, the same active-duty Marine population demonstrated normal glucose homeostasis, suggesting their high levels of total physical activity (a combination of OPA and LTPA) are sufficient to maintain metabolic health (19).

CRF itself is now understood to be a more powerful predictor of mortality than PA levels (2). The "fitness over fatness" principle, supported by meta-analytic evidence, shows that fit individuals have a lower mortality risk regardless of their body weight (1). For example, in a study of physically active U.S. Marines, personnel had normal metabolic health markers (HbA1c) despite a high prevalence of traditional classifiers of overweight and obesity, reinforcing the protective effect of fitness in a military cohort (19).Our study measures PA, a behavior, which is the primary means to improve CRF, the protective physiological state. The fact that LTPA is similarly beneficial for veterans, many of whom likely had high OPA during their service, suggests that the health benefits of leisure-time exercise are crucial for longevity, regardless of prior occupational history. This provides strong evidence that physical activity recommendations derived from the general population are directly applicable to former military personnel.

The primary public health implication of our findings is the reinforcement of LTPA as a universally beneficial and equitable strategy for improving longevity. The absence of interaction indicates that broad, population-wide public health messaging promoting LTPA applies equally to veterans and non-veterans. Efforts should focus on supporting all adults, particularly the nearly 50% who do not meet guidelines, to

increase their activity levels. From a public health perspective, these findings reinforce the broad applicability of physical activity guidelines across diverse population subgroups. The absence of effect modification by veteran status suggests that existing recommendations do not require tailoring based on prior military service or occupational exposure history. Given that a substantial proportion of U.S. adults do not meet recommended activity levels, even modest increases in physical activity, particularly among inactive individuals, could yield meaningful reductions in premature mortality at the population level. These results support continued investment in population-wide strategies to promote physical activity, including community-based interventions and policies that facilitate active lifestyles.

Strengths and Limitations

This study has several key strengths. Its use of a large, nationally representative sample enhances the generalizability of our findings to the noninstitutionalized U.S. adult population. The linkage to the National Death Index provided an objective and complete mortality ascertainment, minimizing detection bias. Furthermore, our analytical approach was robust, employing survey-weighted models to generate accurate population estimates and using restricted cubic splines to flexibly model the dose-response relationship without imposing assumptions of linearity.

This study has some inherent limitations. As an observational study, we cannot infer causality, and the possibility of reverse causation cannot be entirely excluded. Also, our reliance on self-reported physical activity is subject to recall and social desirability biases, which may lead to misclassification and likely attenuation of the true association toward the null (20). We also lacked data on CRF, which is a stronger mortality predictor than PA (1, 2). In addition, NHANES does not capture detailed contextual information regarding activity type, pattern, or conditioning status. We were therefore unable to distinguish habitual recreational exercise from episodic, unaccustomed high-intensity exertion, nor to examine whether associations differed by specific activity modalities. Similarly, our primary outcome was all-cause mortality, and we did not differentiate between natural and external causes of death. Consequently, our findings reflect the net association between reported weekly activity volume and long-term mortality risk rather than the acute risk associated with specific exertional events or cause-specific pathways. Finally, although we adjusted major sociodemographic and behavioral confounders, residual confounding may persist. NHANES does not capture details of military service (e.g., combat exposure, deployment history, specific occupational tasks) or a comprehensive health history, which could independently influence both physical activity and mortality risk and would be needed for a more direct test of the physical activity paradox in this cohort (21).

Conclusion

Higher levels of habitual physical activity are strongly associated with lower all-cause mortality risk in U.S. adults. Even activity levels below current guideline recommendations were associated with lower risk compared with complete inactivity, with the largest relative reductions observed when individuals moved from no activity to even modest weekly volumes. This magnitude and shape of this association were similar in both veterans and non-veterans. These findings support the importance of engaging in

some regular physical activity, rather than none, across the entire adult population, including those with prior military service.

Declarations

Ethics approval and consent to participate

The NHANES protocol was approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board, and all participants provided written informed consent. Additionally, the authors' institutional review board determined this project, involving the secondary analysis of de-identified, publicly available data, to be exempt from its review and not classified as human subjects research, as confirmed in determination letter #26-06-R. The investigators have adhered to the policies for protection of human participants as prescribed in DODI 3216.02, and the research was conducted in adherence with the provisions of 32 CFR Part 219.

Consent for publication

Not applicable

Availability of data and materials

The datasets for this study are publicly available. The NHANES public-use data and public-use Linked Mortality Files are available from National Center for Health Statistics / Centers for Disease Control and Prevention. Data from this analysis is openly available to the public, found here: https://www.cdc.gov/nchs/nhanes/about_nhanes.htm.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. Disclaimer: The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or reflecting the views of the Army or Department of War. Any citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement of approval of the products or services of these organizations.

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Authors' contributions

AWP, WJT, CEM, and KEF designed the research; AWP analyzed data; and AWP, WJT, CEM and KEF wrote the paper. AWP had primary responsibility for final content. All authors read and approved the final manuscript.

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Clinical trial number

Not applicable

Conflict of Interest Statement

The authors have no conflicts of interest.

Data Availability*: NHANES public-use data and public-use Linked Mortality Files are available from National Center for Health Statistics / Centers for Disease Control and Prevention. Data from this analysis is openly available to the public, found here: https://www.cdc.gov/nchs/nhanes/about_nhanes.htm.

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Figures

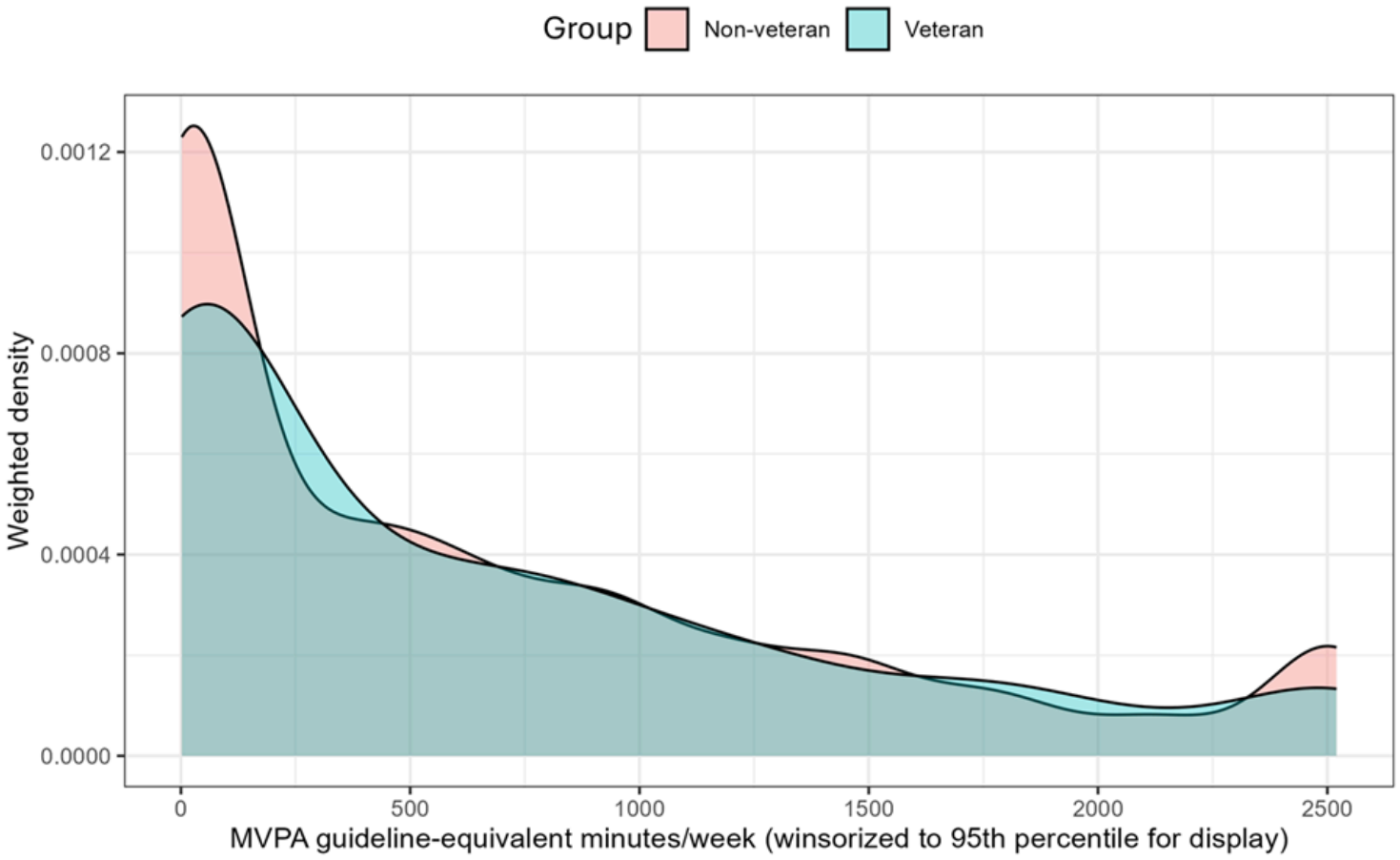


Figure 1

Distribution of moderate-to-vigorous physical activity (MVPA) by veteran status, NHANES 2007–2018.

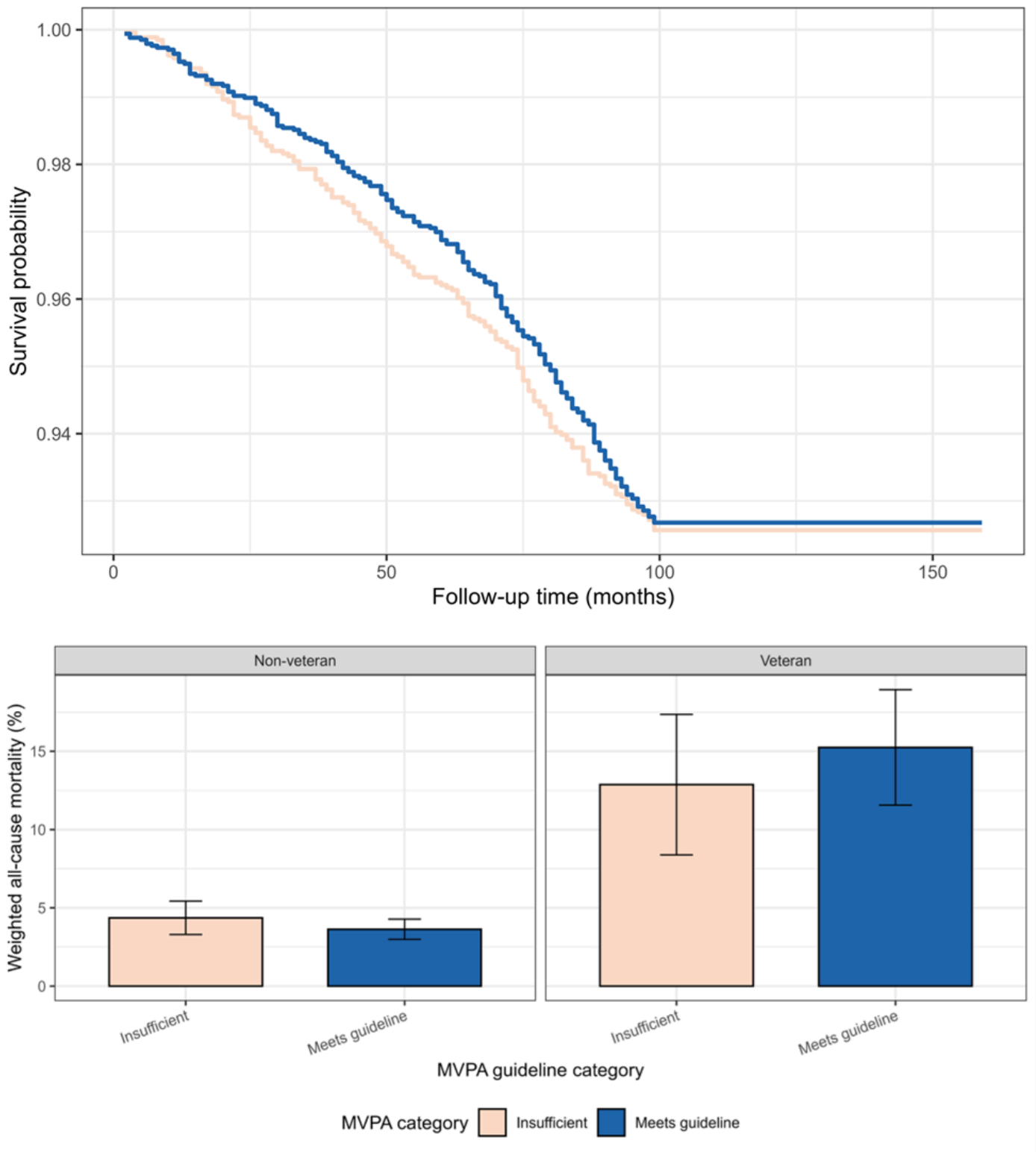


Figure 2

Kaplan–Meier survival curves by MVPA category (top) and weighted mortality percentage by MVPA guideline category and veteran status (bottom).

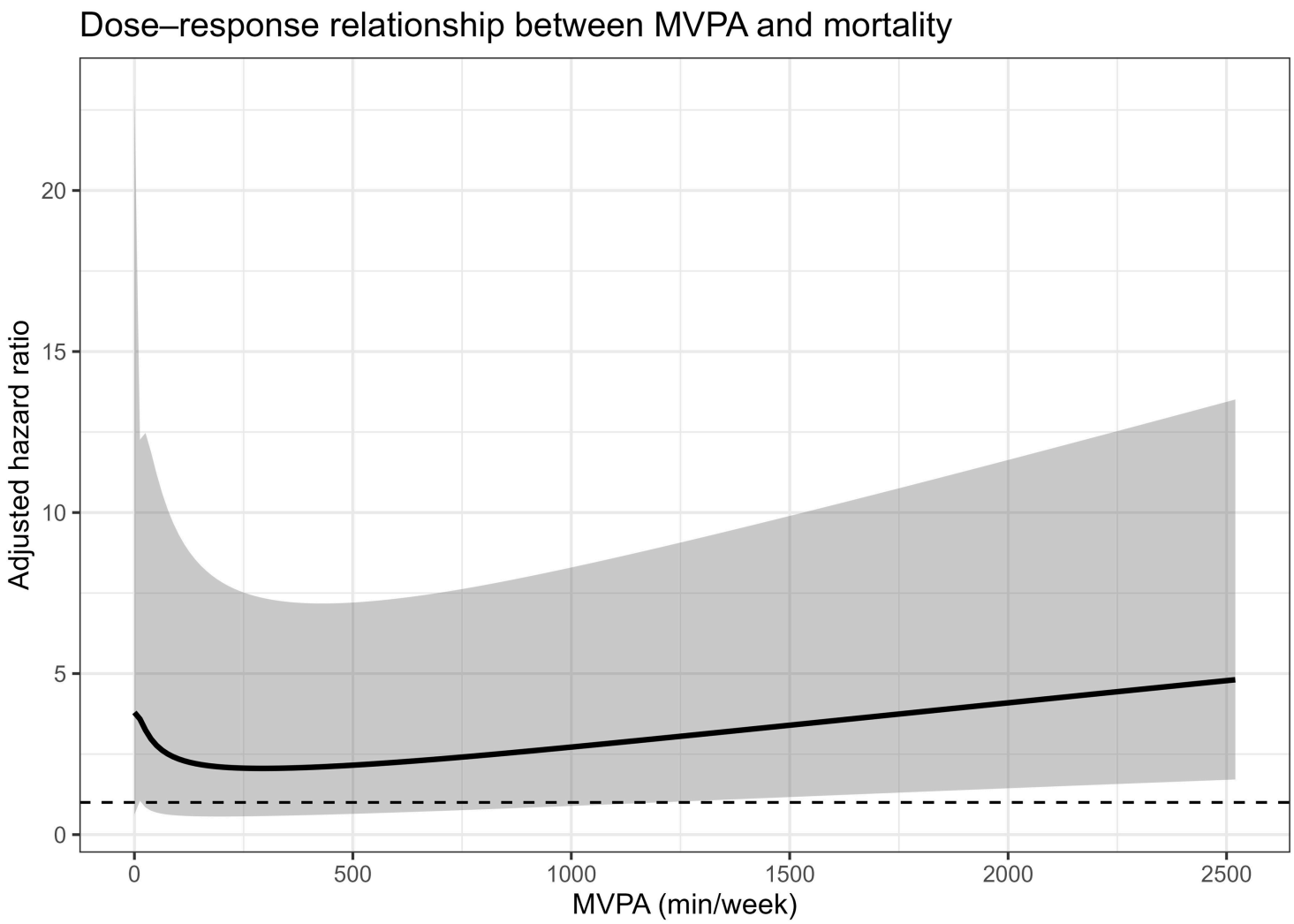


Figure 3

Restricted cubic spline showing pooled nonlinear association between MVPA and mortality risk.

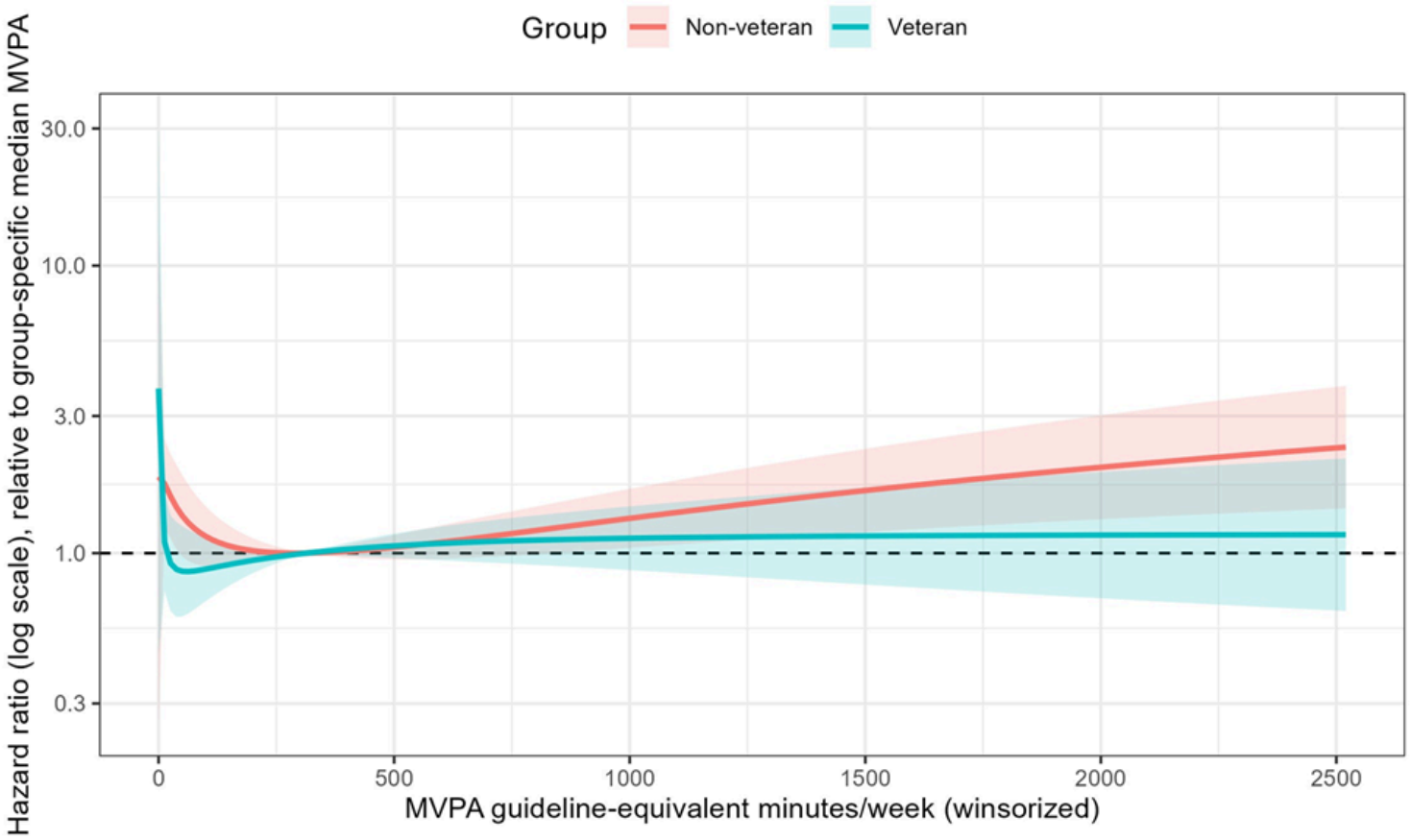


Figure 4

Adjusted hazard ratio curves for MVPA and all-cause mortality stratified by veteran status.