An Evaluation of the Effect of Military Service on Mortality: Quantifying the Healthy Soldier Effect

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PURPOSE: The healthy soldier effect denotes the proposition that military populations are likely to be healthier than other populations. A systematic review was conducted which aimed to quantify the magnitude of the healthy soldier effect.

METHODS: Studies containing mortality rates of military personnel were identified from multiple electronic databases. Studies were included in the meta-analyses if they reported all-cause, cancer, or external-cause mortality in a military population and compared the rates to the general population. Fifty-nine studies were initially identified and 12 were included in the meta-analyses.

RESULTS: The overall meta-standardized mortality ratios (SMRs) for all-cause mortality for deployed veterans was 0.76 (95% confidence interval [CI]: 0.65–0.89) and 0.73 (95% CI: 0.56–1.97) for non-deployed veterans based on a mean follow-up of 7.0 and 2.4 years, respectively; for cancer mortality, the SMRs were 0.78 (95% CI: 0.63–0.98) for deployed veterans and 0.75 (95% CI: 0.50–1.14) for non-deployed veterans based on 6.7 and 3.1 years follow-up, respectively; for external-cause mortality, the SMRs were 0.90 (95% CI: 0.72–1.13) for deployed veterans and 0.80 (95% CI: 0.63–1.01) for non-deployed veterans based on 4.8 and 2.0 years follow-up, respectively.

CONCLUSION: Military personnel do display a healthy soldier effect that decreases their risk of mortality compared to the general population. The overall healthy soldier effect estimated ranges from 10% to 25%, depending on the cause of death studied and the period of follow-up.

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KEY WORDS: Healthy Soldier Effect, Military, Mortality, SMR.

INTRODUCTION

The overall mortality experience of an employed population is known to be more favorable than that of the general population, a phenomenon referred to as the healthy worker effect. The healthy worker effect was first described by William Ogle in an appendix of the Registrar General's report on mortality in England and Wales (1, 2). The most widely accepted explanations for the healthy worker effect (3–9) are self-selection by the employee or selection by the employer. Researchers in the field have estimated the healthy worker effect would reduce the standardized mortality rate across various occupations by 10% to 30% (10).

Military personnel differ from the general population in that they are generally fitter and healthier at enlistment than the general population, leading to a phenomenon referred to as the "healthy soldier effect." This "healthy soldier effect" is analogous to the "healthy worker effect" and denotes the proposition that military populations are likely to be far healthier than other populations.

It has been suggested by Kang and Bullman (11) that a military cohort almost always has better survival rates than a comparable segment of the general population because of initial physical screenings for service, requirements to maintain a certain standard of physical well-being, and better access to medical care during and after military service. There is also evidence to suggest that a healthy soldier effect, related to the exclusion of unfit persons from the armed services, may partly conceal increased morbidity or mortality that should be attributed to war service (12, 13). To date, investigators have recognized the healthy soldier effect, only to dismiss or ignore its significance in reaching final conclusions because there is no clear knowledge of the magnitude of the "healthy soldier effect" on mortality.

A systematic review (Fig 1) was conducted with the primary goal of summarizing the evidence comparing mortality rates of military personnel with the general population and quantifying the magnitude of the healthy soldier effect.

The review aimed to address the following questions:

- What is the size of the difference for all-cause mortality between military personnel and the general population (of the same age and gender)?
- What is the size of the difference for mortality from all cancers between military personnel and the general population (of the same age and gender)?

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Selected Abbreviations and Acronyms

SMR = standardized mortality ratio

- What is the size of the difference for mortality from external causes between military personnel and the general population (of the same age and gender)?

It is hypothesized that there will be a difference between the mortality rates of military personnel compared with the general population.

In this review we use the term “deployed veterans” to mean those who were deployed to a specific conflict, and the term “non-deployed veterans” to mean those who served in the military during a particular conflict but were not deployed to that conflict. Both these groups may include personnel who were on active duty as well as those who were no longer on active duty.

MATERIAL AND METHODS

Studies published between January 1990 and November 2006 were identified from electronic databases, including MEDLINE, PubMed, PsycInfo, and Health and Safety Science Abstracts. The string search utilized can be found in the Appendix.

References of identified studies were searched for further studies, including some papers published before 1980. There was no restriction on the identification of studies in terms of journal quality, but the review was limited to peer-reviewed journal articles printed in English.

Studies were included if they contained data on mortality rates of military personnel. Randomized controlled trials were excluded, but all other study designs were eligible for inclusion provided that an appropriate control or comparison group (i.e., the general population) was included to compare the mortality.

The 3,028 abstracts identified by the original search were screened and the 59 that remained eligible were scrutinized to decide whether they met the inclusion criteria (Fig 1). Studies were excluded if the study population included prisoners of war rather than military personnel, if the study population contained persons younger than 18 years of age, or if the study focused on the effects of a particular exposure (e.g., herbicides, Agent Orange) on mortality and cancer incidence rates. Full copies of 19 papers were then obtained and examined to confirm eligibility and extract data. Data relating to the studies’ main hypotheses, methodological quality, measured outcomes, and results were extracted independently by two members of the research team using a data extraction form that was adapted from the Cochrane data extraction guidelines for cohort studies (http://www.cochrane.dk/nrsmg/guidelines.htm). Extracted data were then aggregated and presented in tabular format. All identified papers that fulfilled the inclusion criteria were categorized by health outcome.

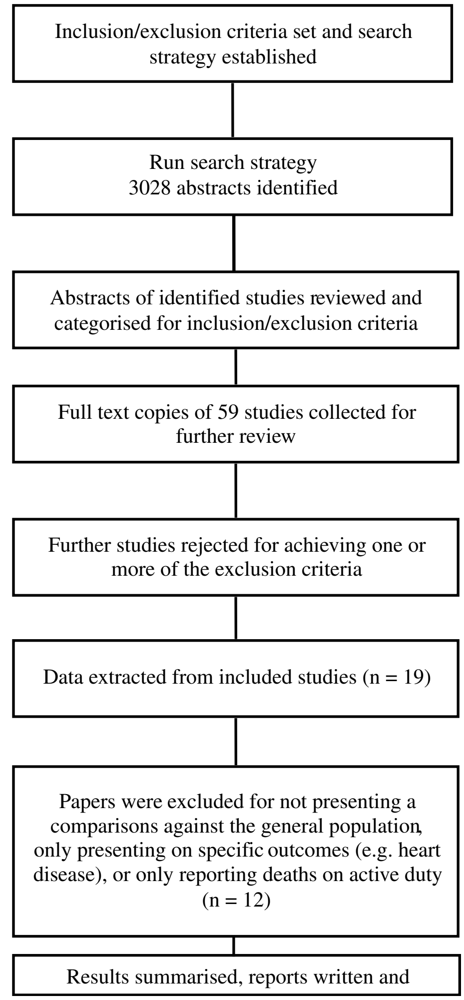

FIGURE 1. Flow chart of the systematic review.

Statistical Analysis

The measure of effect used in this meta-analysis was the standardized mortality ratio (SMR). This compared the mortality of the group in question with that of the general population. Separate analyses were performed for veterans deployed and for military personnel used as comparisons. Meta-analyses were undertaken for all-cause mortality, cancer mortality, and mortality from external causes.

Tests for heterogeneity between the study results were performed using the chi-square (χ^2) statistic. Pooled estimates of the SMR, and the 95% confidence intervals (CIs), were obtained using random-effects meta-analysis (or fixed-effects meta-analysis if there was no evidence of heterogeneity between the study results). Publication bias will occur if relevant studies were not included in the meta-analyses, and the studies missed differed systematically from those identified. This bias was assessed graphically using funnel plots and Egger's test (14).

In the forest plots the SMRs were presented by length of follow-up of each to assess the relationship between the SMR and the length of the study. The study with the shortest follow-up is at the top of the forest plot and the study with the most years follow-up is at the bottom of the y-axis.

The source of heterogeneity was explored using meta-regression. All analyses were completed in STATA 10 (Stata Corporation, College Station, TX).

RESULTS

Nineteen primary studies were identified that investigated the association between service in the military and mortality rates. Of these, 14 compared all-cause mortality between military personnel and the general population (11, 15–27); nine compared cancer mortality in military personnel and the general population (11, 15, 17, 19, 20, 22–25); and 10 compared mortality from external causes in military personnel and the general population (11, 15, 17, 19–21, 24, 26–28). One study reported only on mortality from coronary heart disease (29), and three studies focused on specific types of cancers: sarcomas of soft tissue (30), Hodgkin disease (31), and non-Hodgkin lymphoma (32). These four studies were excluded from the meta-analysis. We excluded one study that looked at mortality patterns in Vietnam veterans because it did not provide person-years to calculate the SMRs (33). Another paper (15) was excluded from the meta-analyses because the same data were analyzed in the study by Fett et al. (18), which was included in the analysis. The paper by Writer and colleagues (27) was distinctive in that only non–battle-related deaths that occurred on deployment during Operations Desert Shield and Desert Storm were reported. A number of the other articles selected explicitly excluded deaths on active duty in their analyses (16, 18, 22, 24, 25). Therefore, this article was not included in the meta-analyses. The paper by Kogan and Clapp (21) presented standardized proportionate mortality ratios. For the purposes of this meta-analysis, these effects were included as SMRs.

Table 1 summarizes the studies that were identified, all of which are described as cohort studies. Five of the 12 remaining papers studied military personnel from the Vietnam War (16, 18, 21, 24, 28), with one focusing specifically on female service members (24). One study focused on military personnel from the Korean War (19), one from the Persian Gulf War (11, 27), and one from World War II (23). Three papers compared military personnel from no specific era with the general population (20, 22, 26), and one paper compared mortality rates within different occupation categories of the British Army (17).

Nine papers presented results of US service members (11, 16, 19, 21, 22, 24, 26, 28, 32), two of UK service members (17, 20), and one of Australian servicemen (18). Mean (or median) age at entry into follow-up was presented in six papers and ranged from 20 to 31 years (11, 16, 18, 22, 24, 28). In each study, comparisons with general population rates were age standardized.

Two papers had a follow-up period of less than 5 years (11, 26); however, these studies had by far the largest sample sizes of all of the research considered. The largest follow-up periods (>30 years) were observed in two studies of the Vietnam deployment and a study of service members who served in Korea (16, 19, 22).

The deployed veterans' data were analyzed separately from the non-deployed veterans because the risk of mortality may have been influenced by exposures encountered on specific deployments.

All-Cause Mortality

Fig. 2, *a* presents the SMRs of all-cause mortality of deployed veterans relative to the general population. The meta-SMR for deployed groups relative to the general population was 0.76 (95% CI: 0.65–0.89) based on an average follow-up of 7.0 years (median 22 years). In all seven studies, the risk of all-cause death was lower in deployed veterans than in the general population. The greatest reduction in mortality was observed in American veterans deployed to the Persian Gulf (SMR 0.44; 95% CI: 0.42–0.47) (11).

Fig 2, *b* gives the SMRs of all-cause mortality in non-deployed veterans relative to the general population. Since the paper by Coggon and Wield (17) contained two groups who were defined by their army occupation (cooks and pay clerks), these groups were included in the meta-analysis as separate studies. The meta-SMR was 0.73 (95% CI: 0.56–0.97) based on an average follow-up of 2.4 years (median, 15.8 years). All but two of the studies had an SMR less than 1, indicating that the military populations had lower all-cause mortality than the general population. The two SMRs greater than 1 were from the aforementioned paper by Coggon and Wield. Cooks and pay clerks had mortality rates higher than the general population (SMR 1.48; 95% CI: 1.30–1.69; SMR 1.06; 95% CI: 0.89–1.24, respectively). When the results of Coggon and Wield are excluded from this analysis, the meta-SMR was reduced to 0.64 (95% CI: 0.49–0.84), with the mean follow-up period unchanged. The largest reductions in mortality were reported by MacIntyre et al. (22) and Fett et al. (18) in studies of serving members in the Vietnam era; by Kang and Bullman (11) in the period of the Persian Gulf War; and by Rothberg et al.

TABLE 1. Characteristics of studies that have reported mortality rates of military personnel compared with the general population

Study	Study design	Measured outcomes	No. included in analysis	Exclusion criteria
Boehmer et al., 2004 (16)	Retrospective cohort study	All-cause mortality; cause-specific mortality	18,581 US Vietnam era service personnel were eligible; 9324 Vietnam era service personnel who served in Vietnam; 8989 Vietnam era service personnel who did not serve in Vietnam	Men who did not enter military service for the first time between 1965 and 1971; men who served more than one term of enlistment; men who did not have at least 16 weeks of active service time; men who did not earn a military occupational specialty other than 'trainee' or 'duty soldier'; men who did not have a pay grade any higher than E5 on discharge from active duty
Coggon and Wield, 1993 (17)	Retrospective cohort study	All-cause mortality; all-cancer mortality; external-cause mortality; specific-cause mortality	1620 Army cooks (U.K.); 1203 Army Pay corps (UK)	Lost to follow up
Fett et al., 1996 (18)	Retrospective cohort study	All-cause mortality	19,209 Australian service personnel who served in Vietnam; 26,957 Australian service personnel who did not serve in Vietnam	Those who enlisted before June 1965 or after February 1971; those who died during Army service within 2 years of enlistment or from combat injuries received in Vietnam; those less than 18 years at age of enlistment; those with clerical errors concerning dates of Army service; those who served for less than 90 days
Groves et al., 2002 (19)	Retrospective cohort study	All-cause mortality; all-cancer mortality; external-cause mortality; specific-cause mortality	40,581 US Navy veterans of the Korean War	Females; duplicate records; death before graduation in 1951
Inskip, 1997 (20)	External cohort study	All cause mortality; all cancer mortality; external cause mortality; specific cause mortality	15,138 Royal Navy submariners (UK)	Lost to follow up (could not be traced)
Kang and Bullman, 1996 (11)	Retrospective cohort study	All cause mortality; all cancer mortality; external cause mortality; specific cause mortality	695,516 U.S. service members who served in the Persian Gulf War; 746,291 U.S. service members who did not serve in the Persian Gulf war	No exclusions
Kogan and Clapp, 1988 (21)	External cohort study	All cancer mortality; external cause mortality; specific cause mortality	840 U.S. service members who served in Vietnam; 2515 US service members of the same era who did not serve in Vietnam	No exclusions
MacIntyre et al., 1978 (22)	Prospective cohort study	All cause mortality (excluding aviation deaths); all cancer mortality; specific cause mortality	800 male aviators (U.S.)	Lost to follow up; died in active duty

(*Continued*)

TABLE 1. (Continued)

Study	Study design	Measured outcomes	No. included in analysis	Exclusion criteria
Rothberg et al., 1990 (26)	Retrospective cohort study	All cause mortality; specific cause mortality; external cause mortality	All 781,000 U.S. Army service members on active duty in 1986	No exclusions
Seltzer and Jablon, 1974 (23)	Prospective cohort study	All cause mortality; all cancer mortality; specific cause mortality	85,491 U.S. World WarII2 Army veterans	No exclusions
Thomas, Kang, and Dalager, 1991 (24)	Retrospective cohort study	All cause mortality; all cancer mortality; external cause mortality; specific cause mortality	4582 female U.S. service members who served in Vietnam; 5324 female U.S. service members of the same era who did not serve in Vietnam or the Pacific theater	Having served between 1965 and 1973; no evidence of Vietnam service; not female; died on active duty; died in a foreign country; no death certificate; could have been involved in treating Vietnam veterans (controls only)
Watanabe and Kang, 1995 (25)	Retrospective cohort mortality study	All cause mortality; all cancer mortality; external cause mortality; specific cause mortality	10,716 U.S. Marine Corps on active duty between 1967 and 1969 who served in Vietnam; 9,346 U.S. Marine Corps on active duty between 1967 and 1969 who did not serve in Vietnam; 5,579 not abstracted	Died on active duty

(16) who assessed mortality of US Army soldiers in a non-combat period (1986).

Cancer Mortality

The SMRs associated with cancer mortality of deployed veterans are collected in Fig. 3, *a*. The meta-SMR for this group of studies was 0.78 (95% CI: 0.63–0.98) based on an average 6.7-year follow-up period (median, 19.3 years). In all but two studies the risk of cancer mortality was lower than in the general population. The two papers with higher cancer mortality in the veterans were both of personnel deployed to Vietnam and were two of the smaller studies included in this meta-analysis (17, 24).

The meta-SMR of cancer mortality of non-deployed veterans relative to the general population indicated that there was a lower risk of cancer mortality in the military group (SMR 0.75 [95% CI: 0.50–1.14]) based on a mean 3.1 years of follow-up (median 16.6 years) (Fig. 3, *b*). The results from the paper by Coggon and Wield, which studied army cooks and pay clerks, contributed SMRs greater than 1 to the meta-analysis (1.41 and 1.16, respectively). If the results reported by Coggon and Wield are omitted from this analysis, the fixed effect meta-SMR is reduced to 0.61 (95% CI: 0.39–0.95) based on the same mean follow-up period.

External-cause Mortality

The overall reduction in deaths from external causes in the deployed veterans relative to the general population was 10% (meta-SMR 0.90, 95% CI: 0.72–1.13) based on an average follow-up of 4.8 years (median, 14.3 years). The two studies in Fig. 4, *a* with an SMR greater than 1 were both studies of Vietnam War veterans (21, 24) and included the study of women personnel. The lowest risk of death from external causes in the deployed veterans group was reported in soldiers of the Korean War (19) and the First Gulf War (11), respectively.

The reduction in mortality from external causes was 20% in non-deployed veterans (meta-SMR 0.80; 95% CI: 0.63–1.01) based on an average follow-up of 2.0 years (median, 15.0 years). The largest reduction in deaths from external causes relative to the general population was reported by Kang and Bullman (11), who investigated U.S. service members at the time of the First Gulf War (Fig. 4, *b*). The two groups that showed an increase in risk of death from external causes in the military population were female U.S. service members in the Vietnam era (24) and Royal Naval Submariners between 1960 and 1989 (20).

Between Study Heterogeneity

In each of the meta-analyses, the chi-square test for heterogeneity was statistically significant; hence Figs. 2–4 present the random effects estimates of the pooled SMRs as opposed to the fixed estimates. Meta regression models were fitted for each of the analyses including the country of the study population (Australia, U.K., or U.S.) and the deployment studied (Vietnam, Korea, Persian Gulf, World War II or ‘no

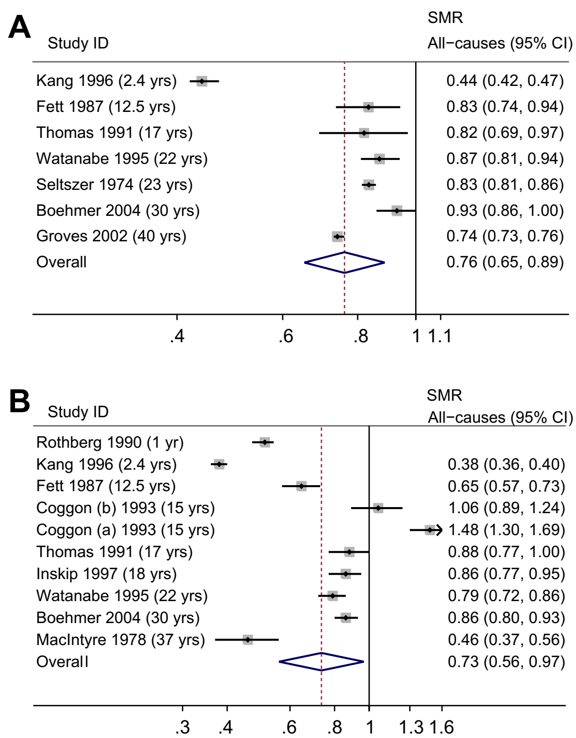

FIGURE 2. **a**, Pooled meta-standardized mortality ratios (SMRs) for all-cause mortality of deployed military personnel relative to the general population. **b**, Pooled meta-SMRs for all-cause mortality of comparison military personnel relative to the general population.

specific deployment') as independent variables. The three studies which investigated the deployment to the Persian Gulf (11), Korea (19), and of U.S. Army soldiers in 1986 (26) consistently showed the lowest SMRs, (that is, the fewest deaths in the military group compared to the general population) compared to the studies of other deployments. In the meta-analyses of cancer mortality and mortality from external causes of military personnel who did not deploy to a specific location, the SMRs from the U.S. studies showed lower mortality relative to the general population than the U.K. studies (which included the analysis of army cooks and pay clerks) (17).

Assessing Publication Bias

Funnel plots were produced for the six separate analyses. None of the funnel plots conformed to a classic funnel shape. This was due in part to the paper on the Persian Gulf War (11), which is one of the largest studies included in the meta-analyses (hence small standard error) but is also the study which shows a large reduction in mortality. The small number of studies included in each separate meta-analysis made interpretation of the funnel plots difficult. Egger's test lacked power to detect asymmetry in these circumstances; however, the lack of symmetry of the funnel

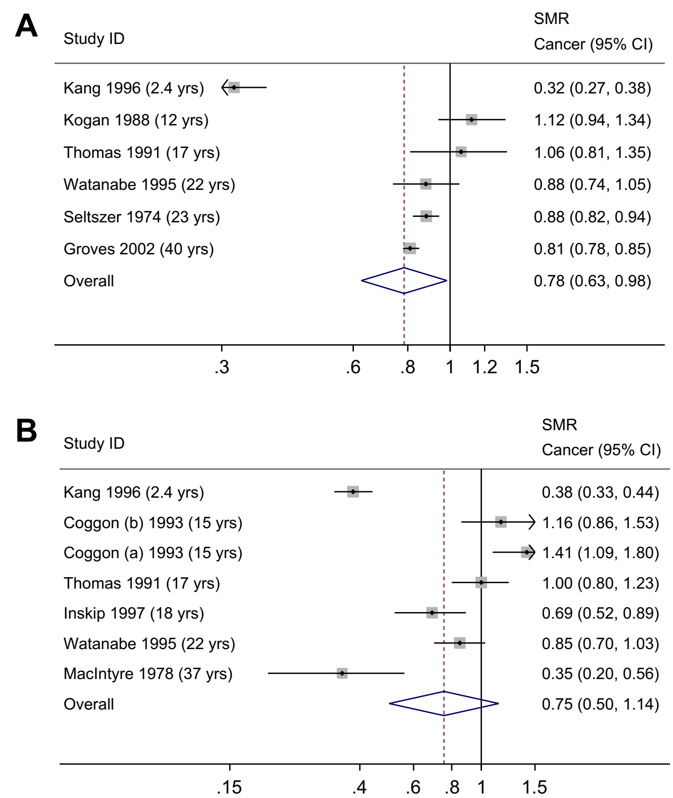

FIGURE 3. **a**, Pooled meta-standardized mortality ratios (SMRs) for cancer mortality of deployed military personnel relative to the general population. **b**, Pooled SMRs for cancer mortality of comparison military personnel relative to the general population.

plots means that the presence of a publication bias cannot be discounted.

DISCUSSION

This review found an overall healthy soldier effect ranging from a reduction in mortality of 10% to 25% depending on the type of mortality studied and the period of follow-up. The reduction in all-cause mortality was similar between deployed veterans relative to the general population and non-deployed military personnel relative to the general population (see Fig. 2). The results for cancer mortality are comparable with reductions of similar size shown for deployed veterans and for non-deployed veterans (see Fig. 3).

The reductions in mortality from external causes are smaller than the all-cause and cancer mortality estimates (see Fig. 4); this is due in part to three studies which showed that the rate of mortality from external causes was higher in the military group studied than in the general population (20, 21, 24).

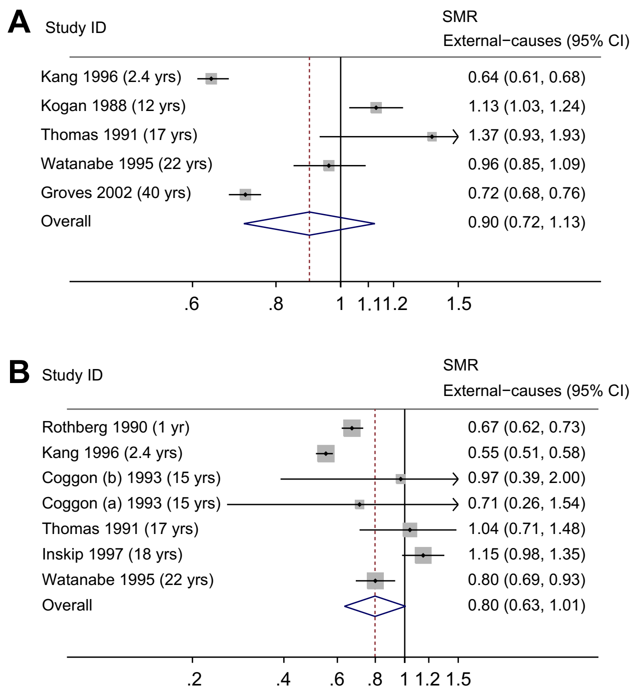

FIGURE 4. **a**, Pooled meta-standardized mortality ratios (SMRs) for external cause mortality of deployed military personnel relative to the general population. **b**, Pooled SMRs for external cause mortality of comparison military personnel relative to the general population.

The largest reduction in mortality in the military groups was observed in the military personnel deployed to the Persian Gulf (11). The military population of U.S. personnel deployed on this operation in the early 1990s would have been very different to veterans conscripted to the war in Vietnam, as would be characteristics of the general population used as comparisons. Hence a large difference in SMRs between these types of studies is not unexpected, and pooling of estimates to produce an overall mean healthy soldier effect may not be best practice.

Two studies which presented poor health outcomes of military personnel were those concerning army cooks and pay clerks in the U.K., and female Vietnam veterans from the U.S. (17, 24). No healthy soldier effect for cancer mortality was demonstrated in the women studied; additionally, a large increase in deaths from external causes was observed (24). This increase in deaths from external causes was due in part to an increased number of deaths from motor vehicle accidents. The study of army cooks and pay clerks reported that cooks had a higher all-cause and cancer mortality rate. It is possible that the cooks may have been a particular high-risk group relative to other military personnel, especially due to lung cancer, as hypothesized by the authors.

The pooled SMRs which compared deployed personnel to the general population were very similar to the pooled SMRs of non-deployed military personnel relative to the background population. It would be interesting to assess the "healthy warrior effect" present in military studies which compare deployed personnel to a comparison group of military personnel who did not deploy to a specific location. However, the assessment of the healthy warrior effect is inherently more difficult to quantify because it is generally unknown what portion of the difference in mortality is due to the healthy warrior effect and how much is due to the effect of deployment.

The estimates of the healthy soldier effect produced may not necessarily be applicable to recent studies of deployment health. The most recent study which included personnel deployed to the Persian Gulf yielded the largest magnitude of the healthy soldier effect. In the absence of papers on deployments that occurred between the end of the Vietnam War and the Persian Gulf War, it is difficult to assess whether military personnel are now healthier relative to the general population than they were in the past.

A limitation of this systematic review and meta-analysis is that it was restricted to peer-reviewed publications in the English language only, and inevitably some relevant studies may not have been included. The effect of excluding studies which were not published in English is unknown. The mortality of the military personnel in other countries may vary depending on the location and the military operations studied. This could be due to the nature of military operations conducted by the forces of different countries or differences in the socioeconomic status of the military populations. Also, the mortality rates in the general population, used as a comparison when producing SMRs, may be different from those in the papers included in this analysis.

By only allowing peer-reviewed literature in the meta-analyses, a number of military studies which may have met the other inclusion criteria have been excluded, resulting in bias. An additional publication bias may be caused by the increase in publications that occurs following high-profile deployments, resulting in a lack of mortality studies of military populations in peacetime.

The SMR estimates used in the meta-analyses were very heterogeneous and likely to be strongly dependent on the type of deployment being studied, the era of the deployment, the nationality of the military force, and the baseline general population. Bias may also result from the differences in the period of follow-up served in the military between the studies. For this reason the pooled SMRs presented in this analysis should not be taken as definitive estimates of the healthy soldier effect for different causes of mortality.

In addition, the follow-up period for each of the studies will have a large influence on the observed SMRs. If the study populations were followed up for an extended time period, one would expect the observed differences in mortality between the military population and the general population to diminish; as a sizeable reduction in mortality at younger ages may be offset with a relative increase in mortality in later life (34).

The study of the Persian Gulf War (11), which showed the largest reduction in all-cause mortality, also had the shortest follow-up period of the papers discussed in this review (approximately 2.4 years). Despite this, there was no consistent indication that the reductions in mortality were smaller for studies with increased follow-up. For example, the Papers by MacIntyre (22) and Groves (19) had 37 and 40 years follow-up, respectively, but still showed large mortality reductions. Seltzer and Jablon (23) noted that although mortality rates gradually approached those of the parent population, mortality effects had persisted 23 years after date of discharge.

It is evident from this meta-analysis that military personnel do display a healthy soldier effect that decreases their risk of mortality compared to the general population of similar age and gender. The overall healthy soldier effect estimated from the pooled SMRs ranges from 10% to 25% depending on the cause of death studied.

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APPENDIX

1. military personnel.mp. or exp military personnel/
2. veterans.mp or veterans/
3. soldiers.tw.
4. (soldiers$ or defence$ or army$ or navy$ or airforce$ or warrior$ or military$ or veterans$ or service$ or exservice$).tw
5. or/1–4
6. epidemiologic studies/
7. exp case-control studies/
8. exp cohort studies/
9. case control.tw.
10. (cohort adj (study or studies)).tw
11. cohort analy$.tw.
12. (follow up adj (study or studies)).tw
13. (observational adj (study or studies)).tw
14. longitudinal.tw
15. retrospective.tw.
16. cross sectional.tw
17. cross-sectional studies/
18. or/6–17
19. (neoplas$ or antineoplas$).ti,ab,rw,sh.
20. cancer$.ti,ab,rw,sh.
21. carcin$.ti,ab,rw,sh.
22. oncol$.ti,ab,rw,sh.
23. sarcoma.ti,ab,rw,sh.
24. exp Neoplasms/
25. (leucaemia or leukaemia or leukemia).mp
26. (adenoma or adenopathy).mp
27. malignant.ti,ab,rw,sh.
28. lymphoma.ti,ab,rw,sh
29. or/19–28
30. exp mortality/
31. exp survival analysis/
32. surviv$.tw,sh.
33. or/30–32
34. 5 and 18 and 29
35. 5 and 18 and 33
36. 34 and 35