Characteristics of the Healthy Worker Effect: A Comparison of Male and Female Occupational Cohorts

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The healthy worker effect (HWE) poses a serious methodological problem to investigators of occupational cohorts in that it may mask mortality excesses that result from occupational exposures. This problem is further complicated by the fact that the strength of the HWE generally varies according to sociodemographic, employment, and time-related factors. While the HWE has been well documented among numerous cohorts of male workers, little is known about its expression among female occupational workers. Follow-up mortality data on 44,154 employees from the Hanford nuclear facility for the period of 1944–1986 were examined using standardized mortality ratio (SMR) analysis to assess whether modifiers of the HWE were expressed differently in females than in males. Results of this analysis show that while the HWE was modified by race, age at hire, occupational class, and length of follow-up in both male and female cohorts, different patterns of modification emerged across the two subgroups. Learning about how gender differentiates expression of the HWE will help investigators more precisely assess the confounding effect of the HWE in studies of working cohorts. Therefore, this study's findings are relevant for designing and interpreting future occupational cohort studies.

The effect of occupational exposures on mortality is frequently assessed by comparing the mortality experience of a working cohort with that of the general US population. Since the general population includes people whose poor health may prevent them from seeking and gaining employment, the mortality rates of any given working population are typically lower than those of the US population.[1–4] This phenomenon, referred to as the healthy worker effect (HWE), poses a serious problem to investigators of occupational cohorts in that it may partially or completely mask mortality excesses resulting from occupational exposures.[1] Understanding how the strength of the HWE varies according to sociodemographic, employment, and time-related factors will help future investigators critically assess the extent to which the HWE is likely to be operative in a given cohort under study. In view of this, a number of investigators have examined modification of the HWE. Their findings indicate that the HWE is particularly strong among nonwhite workers;[4–6] employees hired after age 40,[7,8] and workers of high occupational class.[1,3,9,10] Furthermore, the HWE is reported to become weaker with increased length of follow-up.[1,3,11,12] Comparatively little is known, however, about how the HWE is modified among female working cohorts. The purpose of this investigation is to address this deficit in the literature by comparing modification of the

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HWE in the male and female occupational cohorts.

Methods

Study Population

The study population consisted of 44,154 male and female workers of the Hanford nuclear facility who were hired between 1944 to 1978 and followed until 1986. The major activities of the Hanford site, which is located in southeastern Washington State, include plutonium production, nuclear power generation, advanced reactor generation, advanced reactor design, basic scientific research, research related to the development of nuclear weapons, waste management, and environmental restoration.[13]

The data used in this investigation consisted of analytic files containing demographic, work history, vital status, and radiation exposure information on the Hanford cohort. These files were obtained from the Comprehensive Epidemiologic Data Resource (CEDR), a public-use database established by the department of Energy (DOE) in 1992. Vital status ascertainment for the study population consisted of searches conducted by Gilbert[14] of the Social Security Administration (SSA) earnings and benefits files, deaths reported to the US National Death Index (NDI), and computerized vital statistics files for Washington and California for 1960–1983. For workers on whom vital status information was missing, person-years were counted until the end of study date.

The following occupational class categories were assigned to the study population on the basis of three-digit occupational codes used by the Bureau of Census: (a) professional and technical workers, (b) clerical workers, (c) skilled manual workers, and (d) unskilled manual workers.[14] Workers were assigned to the general category in which they had spent the longest period of time from initiation of employment through the end of 1985.

Using the proportional hazards model, the present study showed that there was no association (hazard ratio = 1.00, 95% confidence interval = 0.99–1.00) between exposure to ionizing radiation and all-cause mortality. Moreover, previous investigators[15] of the Hanford cohort also reported no association between cumulative exposure to radiation and all-cause mortality. Therefore, exposure to ionizing radiation was not adjusted for in this study. Because information on exposures other than radiation was not available for the Hanford study cohort, it was not possible to adjust for the potentially adverse effects of such factors in the present investigation.

Design and Analysis

A retrospective mortality cohort design was utilized in this investigation. Each worker contributed person-years of observation from their date of hire at Hanford until their date of death or the end of the study date (1986). In order to ensure that all workers had the opportunity to accumulate at least eight years of follow-up, workers hired after 1978 were not included in the study cohort.

To estimate the HWE in the study population, standardized mortality ratios (SMRs), were calculated as follows: the ratio of the number of deaths from all causes observed among the study cohort members to the number of deaths expected (based on US rates) with age and calendar year taken into account.[16,17] The United States Death Rates (USDR) computer program,[18] which contains age-, sex-, calendar year–, and race-specific death rates (per 1000 population per year) from the US vital statistics, was used to perform all SMR analyses. Ninety-five percent confidence intervals were generated for each of the SMRs.[18]

Because SMRs are indirectly standardized to different person-time weighting structures, comparison of SMRs across subgroups may produce misleading results.[19] For this reason, the present investigation avoided formal statistical tests and instead relied on a descriptive assessment of the HWE consistent with the method utilized by previous investigations.[3,4,18] Moreover, each study subgroup was examined to assess the extent to which other study factors may have confounded the relationship between the variable of interest and the HWE.

Results

Tables 1 and 2 present descriptive information on male and female Hanford employees respectively. The tables show that for both gender cohorts, the majority of Hanford workers are white and were hired before age 40. Some substantial differences between the two groups are also apparent. For example, while the majority of females are classified as clerical workers, most male workers belong to either the professional/technical or skilled manual occupational classes. Moreover, among males, the subgroups with the latest mean year of hire, and thus the shortest potential follow-up period, are the nonwhite and professional/technical subgroups. Among females, however, nonwhite and skilled manual workers entered the study population substantially later than the other subgroups. These discrepancies may affect the extent to which the HWE is operative in a given subcohort and are therefore important to consider in interpreting the SMR analysis.

Tables 3 and 4 present subgroup-specific SMRs for Hanford males and females, respectively. In each table, the first column presents the overall SMR, and the subsequent columns present SMRs according to length of time since entering the follow-up. Examination of how the HWE changes across length of follow-up strata is important because it permits assessment of how health-selection forces operate in a working cohort over time.[1] Such information is helpful to investigators relying on

TABLE 1
Characteristics of Hanford Males

Variable	n	%	Person-Years	Mean Year of Hire
Entire cohort	31,480	100	775,194	1957
Race				
White	30,306	96	757,779	1957
Nonwhite	1,174	4	17,413	1970
Age at hire				
<40	24,299	77	623,983	1958
40+	7,168	23	151,084	1956
Occupational class				
Professional/technical	14,267	45	307,275	1963
Clerical	2,057	7	51,764	1957
Skilled manual	13,118	42	360,124	1953
Unskilled manual	2,038	6	56,017	1952

TABLE 2
Characteristics of Hanford Females

Variable	n	%	Person-Years	Mean Year of Hire
Entire cohort	12,668	100	334,242	1959
Race				
White	12,047	95	312,583	1958
Nonwhite	619	5	9,614	1971
Age at hire				
<40	11,100	88	294,756	1959
40+	1,565	12	39,102	1957
Occupational class				
Professional/technical	3,072	24	75,880	1961
Clerical	8,349	66	214,208	1960
Skilled manual	592	5	12,294	1965
Unskilled manual	647	5	19,194	1953

SMRs to assess the exposure-disease association in an occupational cohort.

The tables show that both male and female Hanford workers exhibit a strong HWE. Although females exhibit a slightly stronger HWE than males, the point estimates and 95% confidence intervals indicate minimal difference between the two subgroups. The time-related SMRs indicate that Hanford males exhibit a monotonic decrease in the strength of the HWE across the length of follow-up strata. While Hanford females exhibit a similar pattern of monotonic attenuation in the first three strata, they demonstrate an actual increase in the strength of the HWE in the final stratum.

Row 2 of each table, which presents SMRs according to race, shows that in both gender cohorts, nonwhites exhibit a dramatically stronger HWE than whites. Among males the 95% confidence intervals surrounding the race-specific estimates do not overlap. The time-related SMRs show that among males, the white subcohort exhibits a weakening of the HWE over time, while the nonwhite subgroup exhibits no such pattern. It is important to note, however, that because nonwhites entered the follow-up, on average, much later than whites, they had less opportunity for the HWE to wear off. In the female study cohort, both white and nonwhite subgroups exhibit a pattern similar to that of the entire female cohort; that is, a monotonic decrease in the strength of the HWE for the first three decades of follow-up.

Row 3, which presents SMRs according to age at hire, shows that among females, the 40+ subgroup exhibits a stronger HWE than the <40 subgroup, but among males the reverse pattern is exhibited. The time-related SMRs show that among males, no clear pattern was exhibited according to time since entering the follow-up. Among females, both age at hire subgroups exhibit a pattern similar to the entire female cohort.

Row 4, which presents SMRs according to occupational class, shows that the strength of the HWE does not increase monotonically by occupational class for either males or females. The time-related SMRs show that among males all occupational class subgroups except clerical exhibit a monotonic attenuation of the HWE over time. In the professional/technical subgroup, the HWE remains strong, even after 30 years of follow-up. Among females, all of the subgroups except the skilled manual workers exhibit an attenuation of the HWE until the last decade of follow-up, a pattern which is reflective of that exhibited by the entire female cohort.

Discussion

It is widely recognized that the HWE poses a methodological problem to investigators of occupational cohorts.[1-4] Many researchers attempt to circumvent the HWE by utilizing internal comparisons: that is, by directly comparing the mortality experience of subgroups within a defined occupational cohort to one another. Unfortunately, internal comparisons often result in subsamples too small to yield adequate statistical power.[3] Moreover, if an occupational cohort is relatively homogeneous with regard to the occupational exposure under study, identifying meaningful gradations of exposure is not always possible.[11] Finally, if employees are selected on the basis of health-related factors into subgroups that serve as the basis for internal comparisons, then internal comparison bias may occur.[4,14]

TABLE 3

Hanford Males: SMRs According to Years Since Entering Follow-Up*

	Overall	0–9 Years	10–19 Years	20–29 Years	30+ Years
Entire cohort	0.84 (0.82–0.86)	0.66 (0.62–0.70)	0.81 (0.79–0.83)	0.83 (0.80–0.86)	0.95 (0.92–0.98)
Race					
White	0.84 (0.82–0.86)	0.66 (0.62–0.70)	0.80 (0.76–0.84)	0.84 (0.81–0.87)	0.95 (0.92–0.98)
Nonwhite	0.58 (0.48–0.71)	0.40 (0.28–0.58)	0.64 (0.46–0.89)	0.53 (0.33–0.85)	0.76 (0.48–1.18)
Age at hire					
>40	0.81 (0.78–0.84)	0.65 (0.59–0.72)	0.76 (0.70–0.82)	0.72 (0.68–0.72)	0.97 (0.93–1.01)
40+	0.86 (0.83–0.89)	0.67 (0.62–0.73)	0.84 (0.79–0.89)	0.96 (0.91–1.00)	0.91 (0.85–0.97)
Occupational class					
Professional/technical	0.64 (0.61–0.67)	0.55 (0.49–0.62)	0.59 (0.53–0.66)	0.59 (0.54–0.65)	0.79 (0.73–0.86)
Clerical	0.93 (0.85–1.02)	1.00 (0.99–1.00)	0.88 (0.73–1.06)	0.90 (0.77–1.05)	1.00 (1.00–1.01)
Skilled manual	0.90 (0.83–0.98)	0.72 (0.66–0.78)	0.88 (0.87–0.93)	0.91 (0.87–0.95)	0.99 (0.95–1.03)
Unskilled manual	0.92 (0.86–0.98)	0.57 (0.47–0.69)	0.91 (0.80–1.03)	1.00 (0.99–1.00)	1.10 (0.97–1.25)

*95% Confidence intervals are presented for each estimate in parentheses.

TABLE 4

Females: SMRs According to Years Since Entering Follow-Up*

	Overall	0–9 Years	10–19 Years	20–29 Years	30+ Years
Entire cohort	0.81 (0.77–0.85)	0.57 (0.47–0.69)	0.74 (0.64–0.85)	0.89 (0.81–0.98)	0.84 (0.77–0.91)
Race					
White	0.81 (0.77–0.86)	0.59 (0.49–0.71)	0.73 (0.63–0.84)	0.89 (0.81–0.98)	0.84 (0.77–0.91)
Nonwhite	0.50 (0.32–0.79)	0.14 (0.04–0.47)	0.58 (0.27–1.29)	0.94 (0.44–2.02)	0.74 (0.28–1.97)
Age at hire					
>40	0.87 (0.78–0.97)	0.63 (0.50–0.80)	0.81 (0.67–0.97)	0.99 (0.97–1.01)	0.92 (0.83–1.01)
40+	0.78 (0.71–0.85)	0.53 (0.39–0.71)	0.70 (0.57–0.86)	0.91 (0.79–1.05)	0.81 (0.71–0.93)
Occupational class					
Professional/technical	0.79 (0.71–0.88)	0.62 (0.43–0.89)	0.69 (0.52–0.92)	0.89 (0.74–1.06)	0.80 (0.68–0.94)
Clerical	0.82 (0.76–0.88)	0.70 (0.56–0.87)	0.79 (0.67–0.94)	0.89 (0.80–0.99)	0.81 (0.71–0.92)
Skilled manual	0.70 (0.55–0.89)	0.33 (0.13–0.84)	0.44 (0.22–0.90)	0.70 (0.46–1.07)	0.97 (0.67–1.39)
Unskilled manual	0.88 (0.77–1.01)	0.42 (0.24–0.74)	0.91 (0.66–1.24)	1.00 (1.00–1.01)	0.89 (0.72–1.11)

*95% Confidence intervals are presented for each estimate in parentheses.

Oftentimes, even when internal comparisons are feasible, it is informative to compare the mortality experience of a given cohort under study to that of the general population. In view of the aforementioned reasons for utilizing external comparisons, a number of investigators have sought to elucidate the HWE.[2,4,8,11,12] While this phenomenon has been relatively unexplored among male occupational cohorts, little is known about how the HWE is expressed among female cohorts[1,3] or particularly how expression of the HWE differs according to gender. The present investigation examined characteristics of the HWE in a cohort of 44,154 male and female workers at the Hanford nuclear facility in southeastern Washington State.

The strength of the HWE estimates reported for both male and female Hanford workers are consistent with the vast majority of occupational cohort studies[20] and with the findings of nuclear worker cohorts in particular.[21–24] The minimal difference in the strength of the overall HWE between males and females at the Hanford site is consistent with the finding of Carpenter[1] among British nuclear workers, but inconsistent with the findings of Howe and colleagues[3] among a Canadian occupational cohort in which females exhibited dramatically lower all-cause SMRs than males.

A number of investigators[1,3,11,12] have reported that the HWE is strongest during the initial period of follow-up and attenuates steadily over time. This pattern indicates that a strong health-selection force is operative at the time of hire but becomes increasingly less operative over time.[1] For Hanford workers, the attenuation pattern of the HWE is generally consistent with the findings of previous investigations.[1,3,11,12] However, while males exhibited a monotonic decrease in the strength of the HWE throughout the entire follow-up period, females exhibited a stepwise decrease in the HWE for only the first three strata. According to Carpenter,[1] an HWE that fails to attenuate in the later years of follow-up indicates that stable selection forces such as social class or health-related behaviors are operating to confer a health advantage to the working cohort. This, of course, is in contrast to a health-selection effect, which exists exclusively at the time of hire. These discrepant attenuation patterns in Hanford males and females indicate that relative to the general population, Hanford female workers may be more likely than male workers to either exhibit behavior or be part of a social class that confers a health advantage. It will be important to establish whether such gender-differentiated attenuation patterns continue to persist in future occupational cohorts.

Sterling and Weinkam[12] hold that the attenuation of the HWE over time may be attributable in part to accumulation of exposures in the work environment. In view of the lack of association between cumulative exposure to radiation and all-cause mortality among Hanford workers,[14,15] it is unlikely that radiation-exposure effects contributed substantially to the time-related attenuation of the HWE in the present study. However, because data on occupational exposures other than radiation have not been assessed among Hanford workers, their existence and potential confounding effect could not be examined.

This investigation's findings of strong race differences in the HWE are consistent with those of previous investigations among both male[4–6] and female[6] occupational cohorts. The HWE is typically stronger among nonwhite workers because the evaluation of race-specific HWEs is confounded by social class differences in the general US population.[4] In other words, while white workers are compared with the national average white population (with average socioeconomic status), nonwhite workers are compared with the national average nonwhite population (with low socioeconomic status). In short, the social class disparity between employed and unemployed nonwhites is reported to be greater than that between employed and unemployed whites.[4] Given the well-established inverse relationship between social class and mortality,[25,26] it follows that social class differentials across reference populations are likely to result in an amplified HWE for nonwhite workers. This finding suggests that the potential confounding effect of social class on race-specific SMRs should be considered by investigators utilizing external comparisons to assess exposure effects among both male or female occupational cohorts.

While the modifying effect of age at hire on the HWE has not been reported among female workforces, a number of investigators[7,8] have reported that male workers hired after age 40 exhibit a stronger HWE than their peers. Checkoway and colleagues[18] theorized that a worker who seeks and gains employment at an older age is exhibiting nontraditional behavior and is therefore likely to exhibit a level of health superior to that of his/her same-age peers from the general US population. By contrast, a worker who seeks and gains employment at a younger age is less extraordinary in comparison to his/her same-age peers from the general US population. Consistent with previous investigations,[7,5] Hanford females who were 40 or older exhibited a stronger HWE than workers hired before age 40. Interestingly, Hanford males, however, exhibited the reverse pattern. Given that the association between age at hire and the HWE has been relatively well established among male cohorts,[7,8,18] it is likely that the pattern exhibited by Hanford males is anomalous. It will be important, however, to determine whether the present study's findings persist among future cohorts of female workers.

Axelson[9] stated that because health-selection forces are more stringent for more highly qualified jobs, the HWE is generally stronger for higher than for lower-class occupations. Consistent with Axelson's theory, investigators of male and mixed cohorts[1,3,10] have reported that the strength of the HWE increases monotonically with occupational class. The findings of the present investigation show that neither males nor females exhibit patterns consistent with the aforementioned investigations,[1,3,10] that is, a positive and monotonic association between occupational class and the HWE. While Hanford female workers exhibit no discernible pattern between occupational class and the HWE, Hanford males demonstrate a HWE that is considerably stronger in the highest occupational class than in the three lower occupational class subgroups, two of which have relatively small sample sizes. It is important to note that the occupational classification systems used in this study were not identical to those reportedly utilized by previous investigators.[1,3,10] However, in view of the fact that inconsistencies in occupational class criteria did not result in inconsistent findings among the previous investigations, it is unlikely that this investigation's anomalous findings are attributable to measurement inconsistency with previous investigations.

Assessment of time-related expression of the HWE according to occupational class reveals yields some interesting results. Among Hanford females, the skilled manual occupational subgroup, which constitutes only 5% of the total female sample, is the only subgroup to exhibit a monotonic attenuation of the HWE over time. Among Hanford males, the clerical subgroup, which constitutes only 7% of the entire male workforce, is the only subgroup that does not exhibit a pattern of monotonic attenuation over time. Interestingly, the clerical subgroup constitutes the majority (66%) of the female Hanford workforce, while the skilled manual subgroup constitutes 42% of the male Hanford subgroup. In short, these findings suggest that occupational class may be a driving force behind gender-differentiated HWE trajectories over time. Investigation of occupational cohorts that have a more equal distribution of occupations across gender may provide an opportunity to assess whether gender attenuation discrepancies are confounded by occupational class.

Conclusion

The results of these analyses show that while the overall HWE is comparable in the Hanford male and female cohorts, noteworthy gender differences emerge when examining how the HWE is expressed across sociodemographic and time-related factors. In particular, this investigation reveals some potentially important findings with regard to gender and occupational class differentiated trajectories in the HWE over time. The finding that HWE attenuation patterns differ according to gender and occupational class indicates that health-selection processes may operate differently within these subgroups of the study population. Because external comparisons play a prominent role in the assessment of occupational exposure, understanding the characteristics of the HWE will continue to be integral to the proper design and analysis of occupational cohort studies. It will be important to assess whether the patterns revealed in the present investigation persist among future occupational cohort studies. Such information will ultimately help investigators more meaningfully use SMRs to assess the adverse health effects of occupational exposure in both male and female cohorts.

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