Occupational Medicine 2011;**61:**40–44
Advance Access publication on 15 November 2010 doi:10.1093/occmed/kqq168

The healthy worker effect in US chemical industry workers

C. J. Burns, K. M. Bodner, B. L. Jammer, J. J. Collins and G. M. H. Swaen

Department of Epidemiology, The Dow Chemical Company, 1803 Building, Midland, MI 48674, USA.

Correspondence to: C. J. Burns, Department of Epidemiology, The Dow Chemical Company, 1803 Building, Midland, MI 48674, USA. Tel: +1 989 636 2278; fax: +1 989 636 1875; e-mail: cburns@dow.com

Background	Occupational studies typically observe a 20% deficit in overall mortality, broadly characterized as the healthy worker effect (HWE). Components of the HWE may be addressed by various analytical approaches.
Aims	To explore the HWE in a modern industrial cohort.
Methods	Standardized mortality ratios (SMRs) were calculated for 114 683 US chemical industry employees, who worked at least 3 days between 1960 and 2005.
Results	SMRs were 79 (95% confidence interval 78–80) for all causes, 81 (95% confidence interval 79–82) for heart disease, 70 (95% confidence interval 67–73) for non-malignant respiratory disease, 83 (95% confidence interval 81–85) for smoking-related cancers (buccal, cervix, oesophagus, stomach, pancreas, lung, larynx, bladder and kidney) combined and 97 (95% confidence interval 95–100) for other cancers.
Conclusions	The low SMRs observed in this study are likely due to differential smoking between the cohort and the background population. Future considerations to control for the HWE should take this into account.
Key words	Chemical industry; epidemiology; health promotion; healthy worker effect; occupational health; smoking.

Introduction

The 'healthy worker effect' (HWE) describes the observed deficit of mortality and morbidity in occupational cohorts compared with the general population [1–3]. A meta-analysis of >400 chemical industry studies shows a HWE in total mortality [meta-standardized mortality ratio (SMR) = 90] and cardiovascular disease (meta-SMR = 86) [4]. The healthy hire or healthy population effect describes bias from differential hiring, and the healthy survivor or survivor population effect explains bias from differential surviving.

Selection bias, information bias and confounding may contribute to the HWE [5]. Selection bias includes workforce factors that exclude the unhealthy and retain the healthy. Information bias suggests differential diagnostic criteria or incomplete mortality ascertainment. Confounding may arise from determinants of employment. For example, those who are ill may not seek employment, some employers restrict risk factors such as smoking and some have established preventive health programmes. Also, in the USA, access to medical care may be increased by financial well-being or employment.

Bias in studies of occupational exposure and health can be reduced by adjusting the cohort exposure period using lagging techniques, controlling for employment status [6] or using internal populations as a comparison [7,8]. However, internal controls may only control for healthy hire selection bias, rather than information bias or confounding [6]. A recent meta-analysis of benzene-exposed workers used a mortality odds ratio for non-Hodgkin's lymphoma compared to all causes of death in the same cohort to artificially control for the HWE [9]. However, there was no positive disease exposure relationship when all malignant neoplasms were used instead of all causes of death [10].

We recently reported lower than expected mortality in a cohort of chemical industry employees [11]. The large and diverse nature of the cohort allowed exploration of several aspects of the HWE. Although all subjects were chemical industry employees, there was no common chemical exposure. In this study, we address three components of the HWE: selection bias into employment, selection bias out of employment and survivor bias due to continued employment and evaluate their role in predicting mortality.

Methods

We selected subjects from a surveillance database of work histories, demographic information and vital status, of past and present employees of The Dow Chemical Company. Eligible study subjects were employed full time for at least 3 days between 1 January 1960 and 31 December 2005 at 1 of 25 major company locations in 13 states of the USA. We determined vital status from company records and searches with the National Death Index and Social Security Administration. We requested death certificates from the states that permitted this and coded causes of death according to the International Classification of Disease in effect at the time of death. We calculated mortality rates for men and women in 5 year age and time intervals from 1960 to 2005. The Occupational Mortality Analysis Program calculated SMRs based on US rates [12]. We conducted separate analyses for employees with 10 years of follow-up since hire (latency) and for employees with ≥10 years of employment.

Because employees began follow-up throughout the study duration, the potential healthy hire effect was pervasive. A defined fixed subcohort permitted a time lapse or trend analysis of the mortality patterns over time. With the healthy hire effect controlled, and all employees followed equally, the HWE is expected to attenuate as the years of follow-up accrue. We used the 18 867 male employees hired between 1960 and 1969, inclusive. There were few women hired in this decade. Individuals hired before 1960 were excluded in case they were uniquely healthier than their counterparts who terminated employment prior to the study eligibility date [13].

The study was approved by Dow's Human Studies Review Board.

Results

From 114 683 employees eligible for inclusion in the study, there were 28 784 known deaths. Demographic characteristics of the cohort are shown in Table 1. Due to the maturity of the sites under study, nearly a third of the cohort was hired before 1960. Many employees became eligible for follow-up during the 45 year span of the study. One per cent (1524) of the cohort was lost to follow-up.

Table 2 shows low SMRs for all causes of death, very low rates for non-malignant diseases and less so for all cancers. The SMR for smoking-related cancers (buccal, cervix, oesophagus, stomach, pancreas, lung, larynx, bladder and kidney) [14] combined was 83. The SMR for the other cancers was 97.

Figure 1 summarizes the time trends in 5 year increments for those hired from 1960 to 1969. The rates for all cancers approached unity over time from an SMR of 53 during 1965–1969 (8 observed cancer deaths compared with 15 expected) to an SMR of 97 by 2001–2005 (91 cancer deaths compared to 94 expected). The SMRs for non-malignant respiratory disease also increased over time but remained well below 100 (SMR from 25 to 59). The SMRs for heart disease did not change appreciably during follow-up.

Table 1. Demographic characteristics of workers in the study cohort

Characteristic	*n* (%)
Total	114 683 (100)
Sex	
Male	92 951 (81)
Female	21 732 (19)
Unknown	72 (<1)
Race	
White	102 823 (78)
Non-white	11 860 (10)
Unknown	13 999 (12)
Vital status	
Living	84 375 (74)
Deceased	28 784 (25)
Lost to follow-up	1524 (1)
Pay (at last job)	
Hourly and non-exempt	60 168 (52)
Salary	43 475 (38)
Unknown	11 040 (10)
Status at the end of study	
Active	19 217 (17)
Left employment	66 682 (58)
Deceased	28 784 (25)
Hire date	
<1960	35 085 (31)
1960–1969	23 749 (21)
1970–1980	23 461 (20)
>1980	32 388 (28)

Discussion

In a large multi-site US chemical industry cohort, we identified a healthy hire effect for non-malignant diseases. We observed low SMRs for smoking-related cancers but not for cancers unrelated to smoking. Among a fixed subcohort, SMRs for all cancers and non-malignant respiratory disease approached unity over 45 years of follow-up but the HWE for heart disease did not attenuate.

Strengths of this study include its size, with over 3 million person-years of data, and demography. All subjects were chemical industry employees yet represent a wide range of US society from senior management to hourly labourers. A weakness is the absence of individual data on smoking and lifestyle factors, which were not available from company work history records.

Selection bias into employment (healthy hire effect) operates when those hired into the cohort are healthier than the general population. Such bias can operate both at the employer and employee level. For example, applicants who are ill or obese may not qualify for jobs that require physical exertion or mobility. Conversely, as discussed by Le Moual *et al.* [15], individuals with a pre-existing condition such

Table 2. SMR and 95% CI for selected causes for employees with >10 years follow-up or >10 years employment

Cause of death	Entire cohort				>10 years follow-up		>10 years employed	
	Observed	Expected	SMR	95% CI	SMR	95% CI	SMR	95% CI
All causes	28 684	36 251	79	78–80	81	80–82	82	81–83
All malignant neoplasms	8283	9234	90	88–92	91	89–93	92	90–94
All smoking-related cancers	4086	4920	83	81–85				
Buccal cavity and pharynx	110	202	54	45–66	56	46–67	51	40–63
Oesophagus	210	253	83	72–95	84	73–96	87	75–101
Stomach	192	272	71	61–81	71	62–82	76	65–88
Pancreas	428	459	93	85–103	94	85–103	95	85–105
Respiratory system	2680	3246	83	80–86	83	80–86	85	81–88
Cervix	12	21	57	30–100	54	25–102	59	19–138
Kidney	254	229	111	98–125	113	100–128	110	95–127
Bladder or other urinary organs	200	238	84	73–97	84	73–97	83	71–97
All other cancers	4197	4315	97	95–100				
Major non-malignant diseases								
Diabetes mellitus	566	770	74	68–80	76	70–82	76	69–84
Cerebrovascular disease	1520	1906	80	76–84	81	77–85	81	77–86
Heart disease	10 031	12 439	81	79–82	82	80–83	83	81–85
Non-malignant respiratory disease	2090	2986	70	67–73	71	68–74	72	69–75
Bronchitis	326	932	64	57–71	64	57–71	65	57–73
All external causes	1973	2991	66	63–69	69	66–73	65	61–69
People, person-years and deaths								
People at risk				114 683		101 974		64 197
Person-years				3 199 689		2 401 493		1 588 475
Total deaths				28 684		27 790		23 271

One hundred persons who died outside the USA are censored as alive at their end of follow-up because their deaths are excluded from national statistics. CI, confidence interval.

as asthma may selectively choose not to apply for jobs with presumed poor air quality. Other disabilities may prevent educational attainment required for research and management jobs. Since cancer mortality typically occurs many years after employment [16], the healthy hire effect is generally limited to low rates of non-malignant disease. Smokers may similarly avoid entering jobs for which smoking is prohibited or restricted, resulting in low rates of smoking-related disease. Chronic obstructive pulmonary disease (COPD) was recently recommended as a robust indicator for confounding by smoking [17]. In this study, we did not evaluate COPD alone but included it in the deaths attributed to bronchitis. Table 2 shows 326 bronchitis deaths compared with 513 expected (SMR = 64, 95% confidence interval 57–71). The low SMRs for non-malignant diseases, including bronchitis, support a healthy hire effect for this cohort.

Selective bias out of employment may occur if workers voluntarily leave employment due to an existing health problem or concern that work may adversely affect health. Further, employees with high absenteeism may be involuntarily terminated. The resulting bias would suggest increased mortality with shorter duration of employment, whereas long-term employees would have lower SMRs. In this study, SMRs for employees with >10 years follow-up (latency) and those employed for more than 10 years were similar to the SMRs for whole cohort (Table 2), suggesting that selective bias out of employment was not significant in this cohort.

Information bias could lead to incomplete ascertainment of deaths in unhealthy terminated workers compared with the remaining healthy workers. As only 1% of the cohort was lost to follow-up, it is unlikely that this is a significant source of bias in this study. Our findings do not suggest that early termination is a predictor of early mortality or that working longer is protective.

The healthy survivor or survivor population effect suggests better survival rates in those retaining employment. Continued attendance at work could be evidence of an individual's health and well-being. Also, morbidity and mortality may be reduced in the employed by access to health insurance and company-sponsored health programmes

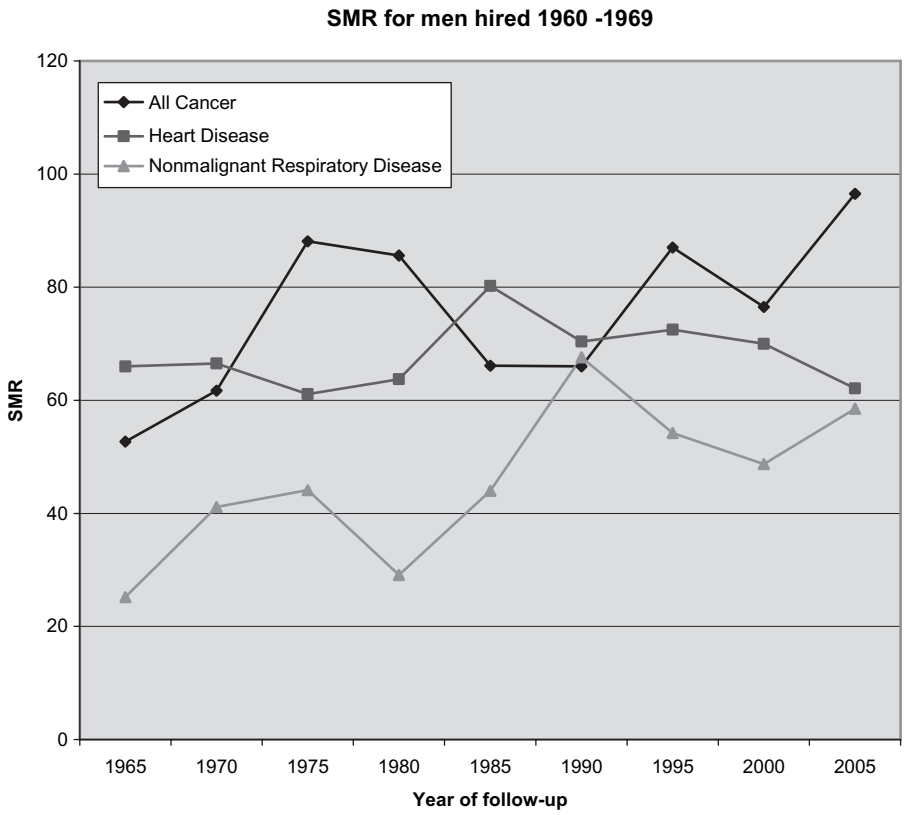

Figure 1. SMRs over time for selected categories of causes of death for employees hired from 1960 to 1969.

as well as the financial advantage of poverty avoidance. Controlling for time-related factors such as age at hire, duration of employment, time since hire and age at risk (or the age at any point of follow-up) may resolve part of this component of the HWE [18]. Lower SMRs would be expected in workers with longer latency (follow-up) and longer employment, but we did not observe such a healthy survivor effect in this cohort (Table 2).

Unlike the vinyl chloride cohort reported by Fox and Collier [19], the increase in cancer SMRs over time in this study (Figure 1) is likely to be a true attenuation of the HWE and not a latent health effect, as suggested by Carpenter [20]. For non-malignant respiratory disease, the rates also increased over time. Despite indications of early selection bias, the mortality risk to the terminated employees becomes increasingly similar to that of the general population [15]. The analysis by Fox and Collier [19] reported that both cancer and non-cancer deaths approached unity after 15 years of follow-up. However, our data for heart disease in this cohort indicate that the HWE persists over 45 years of follow-up. This suggests that behaviours (such as smoking) or risk factor reductions persisted in this group over time and are likely to be confounders.

Attributing mortality deficits to a generic HWE is probably a generalization. There are numerous determinants of health, some of which are related to both employment and survival. Such factors can cause confounding in epidemiological studies. Poverty and underemployment are a critical cause of poor health in the USA [21]. Physically active jobs may be healthier than sedentary ones. Employment, education, income and social class all affect health but these data are rarely available for retrospective cohorts.

Smoking is likely to be an important risk factor affecting the HWE. We observed low rates for cancers related to smoking but not for cancers unrelated to smoking. The one exception was kidney cancer for which the occupational aetiology is unclear in this cohort [11]. Few historical data on smoking rates exist for the company or for the sites under study. A 1984 survey of Texas employees (Freeport and Oyster Creek) demonstrated that 24% of female employees and 29% of male employees were current smokers [22]. This was consistent with self-reported smoking prevalence in Texas but ~7% lower than the USA generally [23,24]. A company Health Assessment Program in 2000–2001 indicated that ~18% of US employees used tobacco compared to 22–28% in the US general population during the same time period [25]. Smoking is not permitted in the workplace at any company facility globally since 2003.

Our findings suggest a healthy hire effect for this large occupational cohort but provide little support for survivor bias. There are important implications of the HWE related to smoking. If the low cancer SMRs observed in this study were due to differential smoking patterns between the study population and the background population, adjustment should account for this in future studies.

Key points

- Occupational studies typically observe a 20% deficit in mortality, broadly characterized as the healthy worker effect.
- We identified an absence of the healthy worker effect among causes of death unrelated to smoking in a large multi-site US chemical industry cohort.
- Differences in smoking prevalence between occupational cohorts and the general population may partly explain the healthy worker effect.

Funding

The Dow Chemical Company.

Conflicts of interest

C.J.B., K.M.B., B.L.J. and J.J.C. hold stock in the Dow Chemical Company, which sponsored this research.

References

1. McMichael AJ. Standardized mortality ratios and the 'healthy worker effect': scratching beneath the surface. *J Occup Med* 1976;**18:**165–168.
2. Industrial Disease Standards Panel. *Reports to the Workers' Compensation Board on the Healthy Worker Effect*. Toronto, Canada: Ministry of Labour of the Government of Ontario, ISDP Report No 3. 1988. http://www.canoshweb.org/odp/html/JUL1988.htm (13 August 2009, date last accessed).
3. Siebert U, Rothenbacker D, Daniel U, Brenner H. Demonstration of the healthy worker survivor effect in a cohort of workers in the construction industry. *Occup Environ Med* 2001;**58:**774–779.
4. Greenberg RS, Mandel JS, Pastides H, Britton NL, Rudenko L, Starr TB. A meta-analysis of cohort studies describing mortality and cancer incidence among chemical workers in the United States and Western Europe. *Epidemiology* 2001;**12:**727–740.
5. Li CY, Sung FC. A review of the healthy worker effect in occupational epidemiology. *Occup Med (Lond)* 1999;**49:**225–229.
6. Arrighi HM, Hartz-Picciotto I. The evolving concept of the healthy worker survivor effect. *Epidemiology* 1994;**5:**189–196.
7. Howe GR. Components and modifiers of a healthy worker effect: evidence from three occupational cohorts, and its application for industrial compensation. In: *Report to the Workers Compensation Board on the Healthy Worker Effect*. Toronto, Canada: Industrial Disease Standards Panel (ODP), IDSP Report No. 3, 1988. http://www.canoshweb.org/odp/html/jul1988.htm (19 January 2010, date last accessed).
8. Leonard RC, Kreckmann KH, Sakr CJ, Symons JM. Retrospective cohort mortality study of workers in a polymer production plant including a reference population of regional workers. *Ann Epidemiol* 2008;**18:**15–22.
9. Steinmaus C, Smith AH, Jones RM, Smith MT. Meta-analysis of benzene exposure and non-Hodgkin lymphoma: biases could mask an important association. *Occup Environ Med* 2008;**65:**371–378.
10. Swaen GMH, Tsai SP, Burns CJ. Meta analysis on benzene exposure and non Hodgkin lymphoma. *Occup Environ Med* 2010;**67:**286–287.
11. Burns CB, Bodner KM, Jammer BL, Collins JJ, Swaen GH. Mortality surveillance of a US wide cohort of chemical industry workers. *J Occup Environ Med* 2010;**52:**982–987.
12. Marsh GM, Youk AO, Stone RA, Sefcik SS, Alcorn CA. OCMPA-PLUS: a new occupational cohort mortality analysis program for multifactor work history and exposure-based analysis. *J Occup Environ Med* 1998;**40:**351–362.
13. Applebaum KM, Malloy EJ, Eisen EA. Reducing healthy worker survivor bias by restricting date of hire in a cohort study of Vermont granite workers. *Occup Environ Med* 2007;**64:**681–687.
14. Thun MJ, Henley SJ. Tobacco. In: Schottenfeld D, Fraumeni JF, Jr, eds. *Cancer Epidemiology and Prevention*. 3rd edn. New York: Oxford University Press, 2006; 217–242.
15. Le Moual N, Kauffmann F, Eisen EA, Kennedy SM. The healthy worker effect in asthma: work may cause asthma, but asthma may also influence work. *Am J Respir Crit Care Med* 2008;**177:**4–10.
16. Doll R. Healthy worker effect. In: *Report to the Workers Compensation Board on the Healthy Worker Effect*. Toronto, Ontario, Canada: Industrial Disease Standards Panel (ODP), IDSP Report No. 3. 1988. http://www.canoshweb.org/odp/html/jul1988.htm (19 January 2010, date last accessed).
17. Richardson DB. Occupational exposures and lung cancer. *Epidemiology* 2010;**21:**181–186.
18. Checkoway H, Pearce N, Crawford-Brown DJ. *Research Methods in Occupational Epidemiology: Monographs in Epidemiology and Biostatistics*. Vol. 13. New York: Oxford University Press, 1989.
19. Fox AJ, Collier PF. Low mortality rates in industrial cohort studies due to selection for workers and survival in the industry. *Br J Prev Soc Med* 1976;**30:**225–230.
20. Carpenter LM. Some observations on the healthy worker effect. *Br J Ind Med* 1987;**44:**289–291.
21. Rehkopf DH, Berkman LF, Coull B, Krieger N. The non-linear risk of mortality by income level in a healthy population: US National Health and Nutrition Examination Survey mortality follow-up cohort, 1988–2001. *BMC Public Health* 2008;**8:**383.
22. Olsen GW, Shellenberger RJ, Lacy SE, Fishbeck WA, Bond GG. A smoking cessation incentive program for chemical employees: design and evaluation. *Am J Prev Med* 1990;**6:**200–207.
23. Marks JS, Hogelin GC, Gentry EM *et al*. The behavioral risk factor surveys: I. State-specific prevalence estimates of behavioral risk factors. *Am J Prev Med* 1985;**1:**1–8.
24. Brackbill R, Frazier T, Shilling S. Smoking characteristics of US workers, 1978–1980. *Am J Ind Med* 1988;**13:**5–41.
25. Saad J. *Online*. http://www.gallup.com/poll/109048/us-smoking-rate-still-coming-down.aspx# (9 October 2009, date last accessed).