Automobile Driver Fatalities in Frontal Impacts: Air Bags Compared with Manual Belts

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ABSTRACT

Objectives. The effectiveness of air bags was estimated in this study by comparing driver fatalities in frontal crashes with driver fatalities in nonfrontal crashes, for cars with air bags and manual belts and cars with manual belts only.

Methods. Fatal Accident Reporting System data for drivers fatally injured during 1985 to 1991 in 1985 to 1991 model year cars that were equipped with air bags in or before model year 1991 were analyzed.

Results. Driver fatalities in frontal crashes in air bag cars were 28% lower than those in comparable cars with manual belts only. This percentage was used for estimating the overall fatality reduction in air bag cars. The reduction was greater in large cars (50%) than in midsize cars (19%) or in small cars (14%). Air bags reduced driver fatalities in frontal crashes involving ejection by about 9%. Fatalities in frontal crashes among drivers who were reportedly using manual belts at the time of the crash were reduced by about 15%. The comparable reduction among drivers who were reportedly not using manual belts was 31%.

Conclusion. It was estimated that air bags reduced the total number of all driver fatalities by about 19%. (*Am J Public Health.* 1993;83:661–666)

Introduction

The value of air bags as an occupant protection feature was hotly debated throughout much of the 1970s and 1980s. However, there is now a strong consensus that the combination of an air bag and a lap/shoulder belt is the best occupant protection system currently available. There is less agreement, however, on the value of air bags when belts are not worn. Increasing numbers of new cars have been sold with air bags, and enough of them have been in severe crashes for their effectiveness in real-world crashes to begin to be quantified.

Federal regulations require that all 1990 and later model-year passenger cars sold in the United States be equipped with automatic restraints.[1] Manufacturers have been able to meet these requirements, which were phased in over 3 years, with either automatic seat belts or air bags. Cars with air bags are also equipped with manual lap/shoulder belts. Increasingly, air bags are being installed as either standard or optional equipment on new cars, primarily on the driver side only. By mid-1991 there were approximately 5.5 million cars on the road with driver-side air bags.

Prior to the current generation of air bag–equipped cars, General Motors provided air bags as an option on a few full-size and luxury car models in the 1970s. In the first major study of real-world crashes involving air bags, Mohan et al. compared injuries in frontal impacts among front-seat occupants who either had air bags, were using lap/shoulder belts, or were unrestrained.[2] Using a statistical relationship between probability of death and Injury Severity Score,[3] Mohan et al. estimated that, in these crashes, air bags reduced the expected number of fatalities per 1000 occupants relative to unrestrained occupants by 79% and relative to lap/shoulder belt–restrained occupants by 26%.

The National Highway Traffic Safety Administration reviewed all the available information and published estimates for the effectiveness of various restraint systems in reducing occupant fatalities in all passenger car crashes (frontal as well as other types). Based on this review, it estimated occupant fatality reductions of 20% to 40% for air bags alone, 45% to 55% for air bags used in combination with lap/shoulder belts, 40% to 50% for manual lap/shoulder belts, and 35% to 50% for automatic belts.[4]

The present study compares fatalities of drivers in passenger cars equipped with air bags against driver fatalities in comparable late-model cars equipped with only manual lap/shoulder belts. It then assesses air bag effectiveness in terms of fatality reductions in crashes that involved frontal impact damage relative to crashes that did not.

Methods

Data

The data analyzed in this study were obtained from the Fatal Accident Reporting System for 1985 to mid-1991.[5] This reporting system is a computerized database that includes virtually all fatal motor vehicle crashes that occur on public roads in the United States.

Because most cars equipped with air bags have them only on the driver's side,

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This paper was accepted with revisions January 8, 1993.

only driver fatalities were included here. The present study is based on fatality counts rather than on fatality rates because it is not possible to obtain meaningful registration counts in the first calendar year that cars are on the road. This means that the first year's fatality experience for particular models cannot be used, leaving insufficient data for a study based on rates at this time.

The make, series, model year, and restraint type for each vehicle were determined from its vehicle identification number using a special-purpose computer program (Vindicator) developed and maintained by the Highway Loss Data Institute.[6] Vehicle identification numbers have a built-in code for identifying cars with air bags. All cars equipped with air bags as optional or standard equipment on or before the 1991 model year were included in this study. For comparison, earlier models of the same make and series (same nameplate) and the same size class with only manual belts were included, if available, back to the 1985 model year. Some car models (e.g., Mazda Miata) were introduced as air bag cars and had no previous manual belt versions. These cars were included in the main analysis to maximize the number of air bag–equipped vehicles in the study. Some cars were equipped with automatic belts for a brief period and later models were equipped with air bags; fatalities in automatic belt cars were excluded. Drivers killed in single-vehicle noncollision events, such as fire, immersion, or gas inhalation, were also excluded.

Classification of Crash, Vehicle, and Driver Factors

Restraint system. Vehicle identification numbers were used to distinguish cars with air bags and to exclude cars with automatic belts.

Damage area. Damage due to the initial impact is coded in the Fatal Accident Reporting System separately from damage due to the principal impact. For both types of impact, damage coded as clock positions 10, 11, 12, 1, or 2 was classified as frontal. All other known damage (e.g., damage represented by specific damage codes other than those listed above) was classified as nonfrontal. Nonfrontal damage includes damage to the side, rear, top, and undercarriage, as well as damage identified as due to underride, override, or rollover without a specific impact point. Cars for which either initial or principal impact points were unknown were classified as unknown and were excluded from all analyses.

Number of vehicles in crash. Crashes were grouped according to whether they involved one or more than one vehicle.

Vehicle size. Vehicle size was defined in terms of wheelbase (rounded to the nearest inch): small (<100 in.); midsize (100 in. to 109 in.); or large (>109 in.).

Other classifications. Crashes were classified by year of occurrence (1985 to 1989, 1990, 1991). Drivers were classified by age (under 30 vs 30 and over), by reported seat belt use (belt used vs belt not used or usage unknown), and by driver ejection (completely or partially ejected vs unejected). The belt use information coded in the Fatal Accident Reporting System has become less reliable since the advent of seat belt laws, but even though the coded information is not completely reliable, it was included in the analysis as a way of assessing the plausibility of findings.

Estimation of Air Bag Effect

Air bags are designed to deploy in crashes in which deceleration along the main vehicle axis exceeds a specified threshold. Thus, in the vast majority of crashes in which air bags deploy, the initial impact, the principal impact, or both impacts will involve frontal damage to the vehicle. In manual belt cars, frontal impacts account for most of all driver deaths, and it is in frontal impacts that air bags are expected to provide maximum benefit. Thus, the location of damage incurred in fatal crashes can be used to assess air bag effectiveness. In this study, an impact was classified as frontal when the initial impact, the principal impact, or both indicated frontal damage.

In a population of cars in which a driver fatality has occurred, the relative frequency of cars with frontal damage should be lower among cars with air bags than among cars with manual belts only. This proposition can be expressed quantitatively using odds ratios. The ratio (R) of the number of drivers killed in cars with frontal damage (F) (i.e., frontal damage in initial *and/or* in principal impact) divided by the number of drivers killed in cars with nonfrontal damage (NF) (i.e., nonfrontal damage in *both* initial and principal impact), R = F/NF, measures the odds that a fatally injured driver was killed in a car with frontal damage. The frontal damage odds ratio is defined as OR = R1/R2, in which R1 is the frontal damage odds for cars with air bags and R2 is the frontal damage odds for cars without air bags. If air bags prevent fatal driver injuries in cars with frontal damage, the frontal damage odds ratio is smaller than 1; if air bags do not prevent such injuries, the frontal damage odds ratio is greater than 1; and if the odds ratio is not statistically different from 1, the evidence is not conclusive.

The standard error for the log odds ratio (log(OR)) was estimated from the numbers of drivers killed in frontal and nonfrontal crashes in cars with air bags (F1, NF1) and in cars without air bags (F2, NF2):

$$SE = (1/F1 + 1/NF1 + 1/F2 + 1/NF2)^{1/2}.$$

Under the null hypothesis that air bags have no effect on the frontal odds ratio, the approximate distribution of the log odds ratio is normal with mean zero and standard error SE. A large negative (positive) value for the test ratio log(OR)/SE would justify concluding that air bags reduce (increase) driver fatalities involving frontal impacts. The magnitude of the test ratio can be assessed using the normal distribution.

The percentage of drivers (PS) whose lives were saved in cars with air bags that had frontal damage was estimated here from the frontal damage odds ratio, PS = 100 × (1–OR).

In the present study, as already noted, crashes are classified as involving frontal damage when *initial and/or principal impacts* were coded as frontal. For cars with multiple impacts, initial and principal damage locations sometimes differ, and air bag effectiveness can depend on whether the initial, the principal, or both impacts were frontal. However, in most crashes, the initial and principal impact points are the same, and the number of multiple-impact crashes in the database was not sufficient to estimate air bag effectiveness separately and with adequate reliability for the various impact-point combinations.

The validity of estimating the percentage of driver lives saved from reductions in the frontal damage odds ratio requires the plausible assumption that air bags exert their influence only on crash outcome and not on crash involvement. In other words, it is necessary to assume that air bags prevent fatalities after deployment, primarily in frontal impacts, but that they do not otherwise modify the mix of impacts in potentially fatal crashes. If this assumption were false—that is, if air bags influence not only the outcome but also the mix of impacts in potentially fatal crashes—fatality reduction estimates based on frontal odds ratio reductions could be biased. However, once one has controlled for the size of the car, there are no documented selection biases that would correlate the presence of air bags with an increase or decrease in the odds for frontal involvement among potentially fatal crashes.

It may be possible for an air bag to deploy and protect the driver of a car that sustained no frontal impact damage in a crash. For example, a side impact could set off an air bag if the longitudinal speed component change exceeded the deployment threshold. However, such crashes would be classified as nonfrontal, and drivers—when protected by air bags—would be counted against, and not for, air bag effectiveness. Because air bag deployment was coded in the Fatal Accident Reporting System as unknown for 65% of all drivers who were killed driving a car equipped with air bag, deployment data were not used in this study.

In the main analysis, some car models that contribute heavily to the manual belt fatality counts contribute little (and sometimes not at all) to the air bag fatality counts, and vice versa. Also, there were relatively few air bag fatalities prior to model year 1987. Thus, as a check on results from this analysis, several further analyses were carried out. These were limited:

1. to model years 1987 to 1991;

2. to model years 1987 to 1991 and to make/series with no significant design change (other than from manual belts to air bag) that might affect occupant protection (see Appendix);

3. to model years 1987 to 1991, to make/series with no significant design change (other than from manual belts to air bag) that might affect occupant protection, and to make/series with at least five manual belt fatalities and five air bag fatalities (which thereby excluded air bag make/series with no previous manual belt version [e.g., Mazda Miata] as well as cars that contributed to only one set of fatality counts); and

4. to model years 1985 to 1991, excluding Mercedes-Benz (which, because of the large number of cars it produces with air bags, makes a major contribution to air bag fatalities and a minimal contribution to manual belt fatalities).

TABLE 1—Driver Fatalities in 1985 to 1991 Model-Year Cars in Crashes 1985 to 1991,[a] with and without Air Bags, and Odds Ratio of Frontal Crash Involvement for Air Bag Cars

Impact Point: Initial	Impact Point: Principal	Fatalities in Cars with: Air Bags	Fatalities in Cars with: Belts	Air Bag to Belt Fatality Ratio	Odds Ratio[b]	Percentage Reduction for Air Bags
Frontal[c]	Frontal	284	4611	0.062	0.71	29
Frontal	Other[d]	38	583	0.065	0.75	25
Other	Frontal	18	200	0.090	1.03	−3
Other	Other	231	2651	0.087	1.00	0

[a]Partial data for first half of 1991.
[b]Computed as fatality ratio for each combination of initial and principal impact points (e.g., initial frontal and principal frontal) divided by fatality ratio for cars with no frontal crash involvement (i.e., other initial impact and other principal impact).
[c]Impacts point between 10 o'clock and 2 o'clock.
[d]Impact point other than frontal.

Results

By the 1991 model year, 169 car series had been equipped with air bags. Among cars for which impact points were known, there were 571 driver fatalities in cars with air bags compared with 8045 driver fatalities in the comparison with manual belt cars. Impact points were not known for 20 air bag cars and 169 manual belt cars with driver fatalities, so these cars were not included in the counts and were excluded from the analyses.

Driver Fatalities by Initial and Principal Impact Points

In crashes with driver fatality and no frontal impact, the ratio of driver fatalities in air bag–equipped cars to fatalities in cars equipped with only manual belts was 0.087. In crashes in which both the initial and principal impacts were frontal, the ratio of driver fatalities in air bag cars to fatalities in manual belt cars was 0.062. Thus, in these crashes, driver fatalities in air bag cars were about 29% less than fatalities in manual belt cars (1 − 0.29 = 0.71 = 0.062/0.087) (Table 1).

In crashes in which the initial impact was frontal but the principal impact was not, fatalities were about 25% lower in air bag cars than in manual belt cars. However, when the initial impact was not frontal but the principal impact was, fatalities were about 3% higher in air bag cars than in manual belt cars. Crashes of the latter type are rare (about 2.5% in the present data set), and the slight increase is likely to represent a chance fluctuation.

Air Bag Effectiveness Estimates Using 1985 to 1991 Data

The ratio of driver fatalities in crashes with frontal impact to fatalities in crashes without frontal impact was 1.47 for air bag cars and 2.03 for manual belt cars. Thus, air bags reduced driver fatalities in frontal crashes by about 28% (1 − 0.28 = 0.72 = 1.47/2.03). Based on the corresponding test statistic (log(0.72)/0.089 = −3.6), this reduction is too large to attribute to chance fluctuation ($P < .001$) (Table 2).

Air bag effectiveness was also estimated separately by ejection status, reported manual belt use, and other driver and vehicle characteristics. Such "subset" estimates are of interest in describing the specific effects of air bags, providing checks for the internal consistency of the results, and relating the results to earlier air bag effectiveness estimates. Because some of these estimates are based on relatively small numbers and because they may vary for reasons not considered here, the estimates presented below should not be considered definitive. To emphasize that they are tentative, the various comparisons were not tested for statistical significance.

Among ejected drivers, air bags reduced fatalities in frontal impact crashes by about 9%; among unejected drivers, this reduction was about 32%.

Among drivers reported in the Fatal Accident Reporting System as using seat belts, fatalities in frontal impact crashes were reduced by about 15%. Among drivers who were reported to be unbelted or whose belt use was reported as not known, the comparable reduction was about 31%. Comparing the reported belt use rates for the two groups of cars in this study is complicated by the fact that air bags prevent fatalities among unbelted drivers. This means that, in any set of fatal crashes, the proportion of all fatalities that are belted will be greater for cars with air bags than for cars with only manual belts.

TABLE 2—Percentage Reduction of Driver Fatality in Frontal Crashes 1985 to 1991[a] for 1985 to 1991 Model-Year Cars with Air Bags, by Selected Crash, Vehicle, and Driver Factors

	Fatalities in Cars with		Odds of Driver Fatality in Frontal Crash		Percentage Reduction for Air Bags	
Cars Included	Air Bags	Belts	Air Bags	Belts	Frontal Crashes	All Crashes
All	571	8045	1.47	2.03	28	19
Driver ejected						
Yes	162	1829	1.28	1.40	9	5
No	409	6216	1.56	2.29	32	22
Reported belt use[b]						
Yes	187	2086	1.37	1.62	15	9
None or unknown	384	5959	1.53	2.21	31	21
Wheelbase length[c]						
>110 in	132	2316	1.28	2.53	49	36
100–109 in	267	4038	1.57	1.93	19	13
<100 in	172	1691	1.49	1.74	14	9
Year of crash						
1985–89	116	5612	1.32	2.02	35	23
1990	264	1765	1.47	2.06	29	20
1991	191	668	1.58	2.05	23	15
Number of vehicles in crash						
One	319	3776	1.40	1.96	29	19
Two or more	252	4269	1.57	2.10	25	17
Driver age, y						
Under 30	231	3144	1.38	1.85	25	16
30 and over	340	4901	1.54	2.16	29	20

[a]Partial data for first half of 1991.
[b]Some 1991 Nissan 300ZX and 300ZX 2+2 cars were equipped with air bags and automatic belts; fatalities in these cars were included.
[c]If a model changed in size class between 1985 and 1991, only the cars in the more recent size class were included.

TABLE 3—Percentage of Reduction of Driver Fatality in Frontal Crashes for Cars with Air Bags, in Selected Subsets

	Fatalities in Cars with		Odds of Driver Fatality in Frontal Crash		
Cars Included	Air Bags	Belts	Air Bags	Belts	Percentage Reduction for Air Bags
Model year 1987–1991	527	3758	1.49	2.04	27
Model year 1985–1991, Mercedes-Benz excluded	478	8024	1.50	2.04	26
Model year 1987–1991, current designs[a] only	527	2940	1.49	2.03	27
Model year 1987–1991, current designs[a] only, five or more driver deaths per make/series with and without bags	295	1921	1.61	2.08	23

[a] See Appendix.

Therefore, the simplest way to compare reported belt use rates in these two groups of cars is to consider belt use in nonfrontal crashes, where it is assumed that air bags have little or no effect. In nonfrontal crashes, reported belt use was about 30% for manual belt cars and about 34% for air bag cars. The reported belt use in nonfrontal crashes also varied over time; for the manual belt cars, it was about 28% in 1989 and earlier years, about 34% in 1990, and about 33% in 1991. The percentage of reported belt use was the same in air bag cars as in manual belt cars in 1989 and earlier years, but it was slightly higher in air bag cars during the last 2 study years.

Air bags reduced frontal impact fatalities by about 49% for drivers of large cars, about 19% for drivers of midsize cars, and about 14% for drivers of small cars (Table 2). In crashes from 1985 to 1989, air bags reduced driver fatalities in frontal impacts by 35%; the comparable reductions during 1990 and 1991 were 29% and 23%, respectively. Air bags reduced frontal impact driver fatalities slightly more among single-vehicle crashes (29%) than among crashes involving two or more vehicles (25%), and slightly more among drivers aged 30 and over (29%) than among drivers under age 30 (25%).

Sensitivity Analyses for Air Bag Effectiveness

Restricting the main data set in various ways and reestimating air bag effectiveness only marginally affected the effectiveness estimates. Overall, air bag effectiveness in frontal crashes was 27% for model years 1987 to 1991 (Table 3). Restricting the data to model years 1987 to 1991 *and* to make/series with no significant design change (other than from manual belts to air bag) had no further effect on the effectiveness estimate; it remained at 27%.

A further restriction to include only make/series with at least five manual belt fatalities and five air bag fatalities resulted in an effectiveness estimate of about 23%. (Note that this analysis may reduce effectiveness estimates for air bags by excluding make/series with few fatalities as a result of their having very effective air bag systems.) Finally, air bag effectiveness in frontal crashes was estimated at 26% for model years 1985 to 1991, using a data set from which all Mercedes-Benz cars were excluded.

About 67% of the drivers in cars with only manual belts were killed in crashes that involved frontal damage—initial, principal, or both (Table 1). A 28% fatality reduction among this population corresponds to a 19% ($0.67 \times 0.28 = 0.19$) reduction in driver fatalities in all crashes (Table 2), which is over and above the fatality reduction attributable to belt use in this sample. Based on all crashes, air bags were estimated to reduce fatalities by almost 21% for unbelted drivers and by 9% for belted drivers (Table 2).

Comparison with National Highway Traffic Safety Administration Estimates

The reported belt use rate among fatally injured drivers of manual belt cars was 26% in this study (Table 2). Assuming this reported belt use is reasonably accurate and that manual lap/shoulder belts prevent 45% of fatalities that would otherwise occur,[4] this implies that 40% of drivers involved in potentially fatal crashes were belted. At this level of belt use, if one uses the effectiveness estimates of the National Highway Traffic Safety Administration, air bags are estimated to reduce driver fatalities by about 22%, which compares with the 19% reduction reported here.

Discussion

After long delays and many court battles, air bags are finally beginning to be provided in quantity in new cars. The present study represents a first step toward the long-term goal of comprehensive, scientific documentation of the effects of air bags on occupant injuries. In this study, air bags were estimated to prevent 19% of the driver fatalities that would otherwise have occurred; this represents 28% of the driver fatalities that would have occurred in frontal crashes.

Applying the 19% reduction for all crashes to cars that are currently equipped with driver-side air bags, it can be estimated that the air bags already in cars had prevented approximately 130 driver fatalities by mid-1991. In future years, more models of passenger cars, as well as additional types of vehicles, will be equipped with air bags. Based on the results of this study, if all passenger vehicles (cars, pickups, vans, and utility vehicles) had had similarly effective driver-side air bags in 1990, about 18 000 drivers would have been killed in crashes that year—4000 fewer than the nearly 22 000 who did actually die.[7]

The 49% reduction estimated here for large cars is near the midpoint of the 79% estimate for unrestrained and 26% estimate for restrained drivers in Mohan et al.[2] Given that the two studies differ in definitions of frontal impact, type of data used, car populations, methods of analysis, and the statistical uncertainties inherent in estimates based on relatively small samples, the agreement between the two estimates is quite remarkable.

The range of effectiveness found for different size cars—49% for large cars but only 14% for small cars—probably reflects several factors. Large cars are predominantly expensive four-door models, and among small cars are many sports models and convertibles. Compared with other body styles, sports models tend to have a higher proportion of single-vehicle frontal crashes at high speeds, at which the effectiveness of restraint systems declines rapidly.

In a study not based on air bag crash data, Evans estimated the effectiveness of air bags alone in preventing fatalities in passenger cars at about 18% for drivers and about 13% for right front passengers.[8] The key assumptions used by Evans to derive these estimates were that air bags do not prevent fatalities in crashes involving ejections, and that they protect only in frontal or near frontal crashes, with injury-reducing effectiveness equal to that of lap/shoulder belts. The air bag effectiveness estimates found in this study are slightly higher than those reported by Evans but are also somewhat lower than the midpoint estimates of the National Highway Traffic Safety Administration (see Introduction).[8] The best estimates from the present study are that air bags alone reduce fatalities for all drivers by about 21% and for belted drivers by about 9%. It has been found in observational surveys that drivers in cars equipped with air bags use seat belts about as much as drivers in late-model cars equipped with manual belts only.[9–11]

Air bag effectiveness has not yet been reliably estimated for right front passengers. Assuming similar air bag effectiveness rates as for drivers, it can be estimated that, had air bags been available on all passenger vehicles in 1990, they would have saved more than 1400 of the approximately 7500 front-seat passengers who died in crashes in that year.[7]

Air bag effectiveness was estimated here in terms of reduced driver fatalities in crashes that had frontal impact damage compared with fatalities in crashes that did not have frontal damage. This distinction made it possible to provide initial estimates much sooner than would have been possible using registration-based crash rates. However, this methodological choice required that an a priori assumption be made about the lack of air bag effectiveness in nonfrontal crashes. While reasonable, such an assumption is probably conservative because air bags may save the lives of some drivers in crashes that do not involve frontal impact damage.

Because of study limitations, any assessments of the statistical significance for various factors should be treated as tentative, and the potential importance of variables or interactions omitted from the study should not be ruled out. However, this study shows that the long-awaited promise in lifesaving benefits of air bags is already a reality. □

Acknowledgments

The authors gratefully acknowledge the following Insurance Institute Highway Safety staff members for their assistance with this project: Marvin Ginsburg for data processing; Sharon Rasmussen for editorial assistance; William Gouse for vehicle classifications; and Allan Williams, Adrian Lund, and Brian O'Neill for helpful discussions.

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APPENDIX—Definition of a Design Break

A design break was defined as major revisions to the body, with or without changes in the powertrain or chassis. Major body revisions included changes to the vehicle's front-end sheet metal, doors, occupant compartment, and underbody. Wheelbase changes were classified as design breaks. Revisions to accommodate air bags, powertrain configurations, chassis modifications, and interior changes were not classified as design breaks unless they were part of a new exterior body design. (Models of the Porsche 911 were reclassified beginning in 1989 because, although the body design and wheelbase remained the same as in earlier models, there were other major changes in the chassis.)

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Errata

In: Guidotti TL, Jacobs P. The implications of an epidemiological mistake: a community's response to a perceived excess cancer risk. *Am J Public Health*. 1993;83:233–239.

In Figure 1, there is a transposition in the key. Closed dots should be associated with the affected community and open dots with the comparison community.

In: Buehler JW, Hanson DL, Chu SY. The reporting of HIV/AIDS deaths in women. *Am J Public Health*. 1992;82:1500–1505.

In Figure 3, the vertical axis is mislabelled. The death rates shown are per 100 000 population, not per million population. The units given in the text are correct.