Estimates of Motor Vehicle Seat Belt Effectiveness and Use: Implications for Occupant Crash Protection

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Abstract: Estimates of the effectiveness of seat belts, when used, in reducing motor vehicle occupant deaths vary widely. A recently publicized claim by one analyst that seat belts reduce vehicle occupant deaths 70–80 per cent is based on studies found to contain fundamental systematic error. Deaths occur only 50 per cent less often to belted compared to nonbelted vehicle occupants in crashes, according to previously unanalyzed data from three U.S. states during recent years. New belt systems would be about 60 per cent effective with 100 per cent use. But surveys of observed belt use in 1975 U.S. cars indicate that two-thirds of drivers were not using belts. Prospects for widespread adoption and enforcement of belt use laws in the U.S. are not encouraging. Substantial reductions in fatal and other injuries would result from the adoption of requirements mandating automatic (passive) protection for front seat occupants in crashes with forward decelerations. (Am. J. Public Health, 66:859–864, 1976)

Precise measurement of the effectiveness of seat belts, when used, in reducing injuries has eluded researchers. Studies generally agree that belts reduce injuries but the range of estimated effectiveness is broad. Sources of systematic error in estimates of seat belt effectiveness are known, but no study has adequately eliminated all sources of systematic error. This paper summarizes the known sources of error and examines studies of belt effectiveness and belt use in light of this knowledge. Despite the uncertainty regarding exact belt effectiveness, reasonable conclusions regarding systems to protect motor vehicle occupants can be drawn.

Sources of Error in Effectiveness Estimates

The numerous studies attempting to estimate belt effectiveness in real-world crashes have followed a similar strategy. Injuries in crashes to occupants of vehicles believed to be wearing belts are compared to injuries of occupants believed not wearing belts. Two errors can seriously bias effectiveness estimates: (1) the presence or degree of injury results in erroneous reporting or claims of belt use; (2) the presence or degree of injury affects inclusion of crashes in the studies.

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Although not an error in the strictest sense, variation in belt effectiveness estimates can also occur because belt use is more frequent or has different effects in crashes that involve differences in vehicles, differences in belts or other equipment, differences in occupants, or differences in crash configuration and severity.

A small systematic bias in *claimed* as compared to *actual* belt use in crashes can affect the estimated effectiveness of belts substantially.[1] A completely objective means of measuring use, such as by automatically recording forces on belts in crashes, has not been employed. Crash investigators attempt to measure belt use by observation where possible, or by observing injury patterns and questioning persons involved. However, it is well known that claimed belt use by persons not involved in crashes is considerably in excess of actual use. In a North Carolina study, 23 per cent of drivers who claimed in a questionnaire to use belts "always" on local trips were not using them when observed in their cars near their homes. Of those who claimed to use belts "always" on long trips, 54 per cent were not using belts when observed on highways distant from their homes.[2]

It is quite likely that some vehicle occupants in crashes tell investigators that they were wearing belts when they were not doing so. It is also likely that belt use is actually observed among the more severely injured who remain in their vehicles but is obtained by interview from those with nonsevere or no injury. The potential effect of this bias on estimates of belt effectiveness is illustrated with hypothetical data in Table 1. If only 5 per cent (500) of vehicle occupants claim to use belts when they actually do not and those persons are not injured, severe-injury belt effectiveness estimates would be substantially higher than actual effectiveness (53 per cent vs. 40 per cent).

Some early studies of belt effectiveness included only crashes involving injury. If belts eliminated injuries in some crashes, then those crashes were systematically excluded from the denominator.[3] The hypothetical data on Table 1 show 40 per cent effectiveness in severe injury reduction based on all occupants. However, when only the per cent seriously injured of those injured are considered, belts appear to reduce severe injuries by only 22 per cent. To the degree that those for whom the belts reduced injuries were excluded in belt effectiveness studies, belt effectiveness was systematically underestimated.

One example should suffice to illustrate the biases in belt effectiveness estimates resulting from lack of consideration of vehicles, equipment, occupants, crash configurations, and severity of injury. The possible bias that could occur from studies that combine less severe injuries with more severe injuries in estimating belt effectiveness is illustrated with the hypothetical data in Table 1. In the hypothetical data, belts are more effective in preventing severe injuries (40 per cent) than in preventing minor injuries (20 per cent). The estimate obtained by combining severe and minor injuries (23 per cent) would result in underestimation of belt effectiveness in reducing the more severe injuries.

TABLE 1—Hypothetical Data Illustrating Potential Systematic Errors in Estimating Belt Effectiveness

	Belt Use		
	Belted	Unbelted	Total
All Vehicle Occupants in Crashes	2,500	7,500	10,000
No Injuries	2,040	5,700	7,740
Minor Injuries	400	1,500	1,900
Severe Injuries	60	300	360
Per Cent Severe of All Occupants	2.4	4.0	
Per Cent Severe and Minor of All Occupants	18.4	24.0	

If All Occupants Are Considered

Estimated Belt Effectiveness in Reducing Severe Injuries = $\frac{4.0 - 2.4}{4.0}$ = 40.0%

If 500 Noninjured Occupants Claimed to Use Belts When Did Not

	Claimed Belt Use	
	Belted	Unbelted
All Vehicle Occupants in Crashes	3,000	7,000
Per Cent Severe of All Occupants	2.0	4.3

Estimated Belt Effectiveness in Reducing Severe Injuries = $\frac{4.3 - 2.0}{4.3}$ = 53.5%

If Only Injury Cases are Used to Estimate Effectiveness

Estimated Belt Effectiveness in Reducing Severe Injuries = $\frac{16.7 - 13.0}{16.7}$ = 22.1%

If All Injuries Rather than Only Severe Injuries are Used to Estimate Effectiveness

Estimated Belt Effectiveness in Reducing All Injuries = $\frac{24.0 - 18.4}{24.0}$ = 23.3%

Estimates of Relative Biases: A Case History

In a letter to the Director of the National Highway Traffic Safety Administration (NHTSA), an analyst claimed that reanalysis of 19 prior belt effectiveness studies indicated 70–80 per cent effectiveness of belts in reducing fatalities—substantially above NHTSA estimates.[4] He emphasized the bias that can occur from combining fatalities with less severe injuries. However, other sources of error were ignored. The letter was publicized[5] and a Michigan Congressman claimed that the new belt effectiveness results negated the need for automatic crash protection such as air bags.[6]

The 19 studies are summarized with respect to claimed belt use and effectiveness in Table 2. It is evident that estimated effectiveness varies widely. Estimated belt effectiveness in death reduction if everyone wore belts ranges from 7.5 to 85.6 per cent.

The claim that belt effectiveness has been underestimated was based on the distribution of estimated per cent effectiveness in the 19 studies relative to per cent of occupants excluding those with the most serious injuries as in Figure 1. The tendency for effectiveness estimates to be lower when wider ranges of nonfatal injuries were included in the calculation of effectiveness led to the conclusion that belt effectiveness had been generally underestimated. The clustering of fatality reduction estimates above 70 per cent led to the publicized claims that belts are 70–80 per cent effective in reducing fatalities.

However, the error that would inflate the estimates of effectiveness was ignored. The effectiveness estimate states the reduction in injuries for everyong wearing belts compared to everyone not wearing belts. Thus, effectiveness estimates should not be correlated with per cent belt use. Yet as indicated in Figure 2, estimates of belt effectiveness in the 19 studies are much higher when *claimed* belt use is relatively high. As the example given in Table 1 has shown, this would be expected if some percentage of persons with minor or no injury claimed falsely to be using belts when they were not—resulting in erroneously high estimates of belt effectiveness.

Furthermore, when the effects of claimed belt use and different severity categories were examined simultaneously, differences in claimed belt use accounted for much of the difference in estimated effectiveness. The effect of grouping less with more serious injuries was attributed to chance fluctuation in sampling (See Appendix). The most probable scientific explanation of these findings is that the higher effectiveness estimates among the 19 studies are grossly in error because of false belt use claims.

The 19 studies were done in a number of countries at widely differing times. The conditions of vehicles, vehicle mixes, road environments, passengers, and the like could contribute to considerable variation in belt effectiveness even without the error found in claimed belt use.

TABLE 2—Claimed Belt Use and Estimated Effectiveness in 19 Studies

Author(s)	Per Cent Claimed Belt Use	Per Cent in Most Serious Injury Grouping*		Estimated Per Cent Effectiveness	Per Cent Occupants Excluding Most Serious Injury Grouping
		Belted	Unbelted		
Anderson[7]	7	3.7	3.9	7.5	96.1
Andreassend[8]	42	6.1*	11.1*	45.1	91.0
Andreassend[8]	50	0.4	1.4	72.1	99.1
Bohlin and Andersson[9]	24	0.0†	0.2	82.8	99.9
Campbell[10]	9	8.3*	12.5*	33.8	87.9
Commonwealth Bureau[11]	11	0.8	1.8	54.3	98.3
Council and Hunter[12]	19	5.3	11.3	52.8	89.9
Highway Safety Foundation[13]	33	0.1	0.7	81.4	99.4
Kahane[14]	19	0.2	0.6	72.5	99.5
Kihlberg[15]	17	0.8	1.1	26.1	99.0
Levine and Campbell[16]	16	5.4*	10.4*	48.4	90.4
New York State[17]	56	0.05	0.3	85.6	99.8
Preston and Shortridge[18]	22	3.7	6.5	42.3	94.1
Richardson[19]	33	0.7	1.7	58.9	98.6
Road Traffic Board[20]	27	0.1	0.3	67.5	99.7
Scott[21]	44	6.2*	11.7*	46.5	90.7
Tharpe[22]	4	11.8*	15.0*	21.5	85.1
Tourin and Garrett[23]	10	0.4	0.7	38.3	99.3
Washington State Patrol[24]	27	0.1	0.6	80.0	99.6

†Less than 0.05 but not 0.
*"Serious" nonfatals included where indicated by asterisk; otherwise percent fatal is presented.

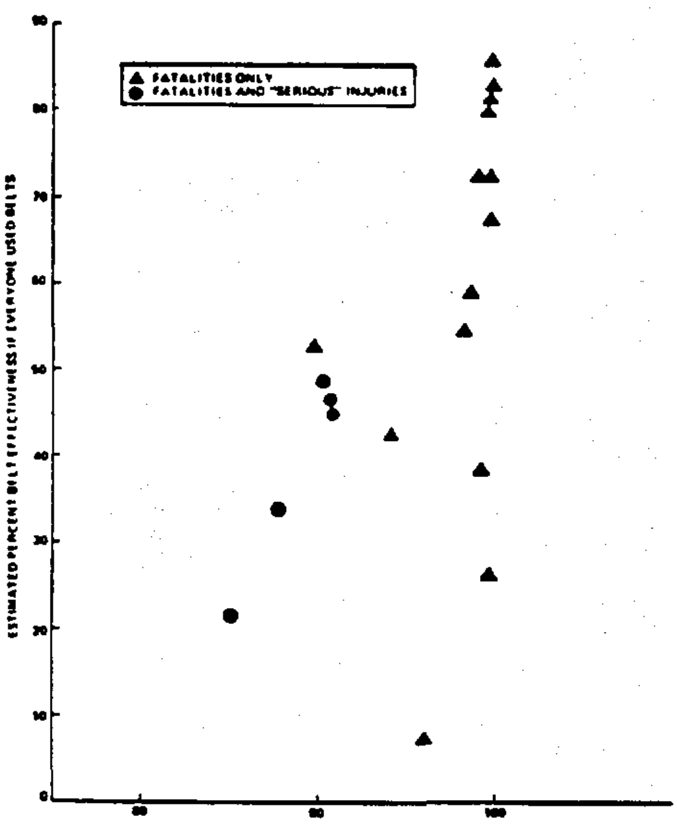

FIGURE 1—Estimated belt effectiveness as a function of relative seriousness of injuries in cases included in 19 studies

New Data

Previously unanalyzed data on belt use in crashes in the present U.S. road environment do not support the claim of 70–80 per cent effectiveness. In recent years, the police in Arizona (1967–1974), Nebraska (1967–1974), and Virginia (1969–1974)[25–27] have recorded claimed or observed belt use in the majority of their crash reports. Estimates of belt effectiveness in reducing fatalities based on these data cluster around 50 per cent. Figure 3 presents the estimated per cent effectiveness in fatality reduction in relation to claimed belt use in these states during each of 7 years in two states and 8 years in a third. Estimated belt effectiveness is uncorrelated to claimed use. Thus, that source of error does not contribute to the variation found as it did in the 19 prior studies. (It cannot be ruled out, however, because it could conceivably be the same in each state and affect each estimate uniformly.) Confidence in these studies is also greater compared to the 19 prior studies because claimed belt use clusters within a relatively narrow range and is closer to that observed in various surveys.[28]

It was not possible to separate lap from combined lap and shoulder belt use in the data from Arizona, Nebraska, and Virginia or in the prior 19 studies. Data from a more recent study[29] of 1973–1974 model cars in towaway crashes indicating substantial differences in injury reduction depending on type of belt and direction of impact are displayed in Table 3. Lap belts reduced severe injuries only 17 per cent in front and front-angle crashes compared to 46 per cent in side, rear, and rollover crashes. Lap and shoulder belts in combination reduced severe injuries 58 per cent in front and front-angle crashes compared to 62 per cent in side, rear, and rollover

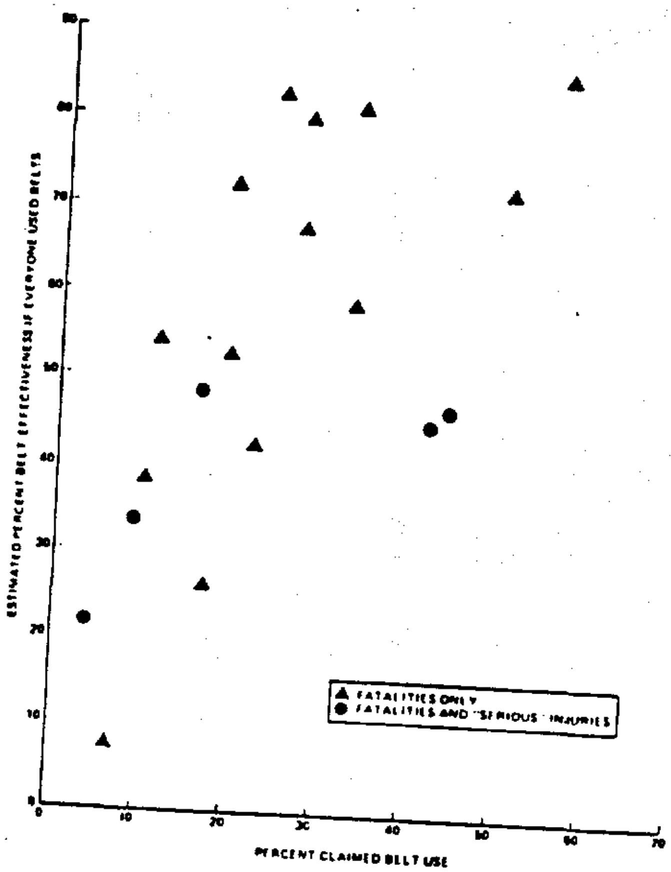

FIGURE 2—Estimated percent effectiveness of belts as a function of calimed belt use—19 studies from various countries

crashes. However, such reductions can only be gained with 100 per cent belt use.

Prospects for Belt Use

Prospects for increasing belt use in the U.S. are not encouraging. A carefully controlled study of an advertising campaign found no effect on belt use.[30] The buzzer-light reminder system on some 1972 and most 1973 cars did not increase belt use significantly.[31] In response to automobile manufacturer lobbying, the ignition-interlock system that prevented the vehicle from starting unless the belts were extended four inches or latched was required on 1974 cars. The interlock system increased belt use in new cars to near 60 per cent in early 1974.[32] However, in late 1974 a federal law was enacted banning the ignition-interlock and continuous buzzer-light systems as federally required equipment on new cars.

In early 1975, the author conducted a belt use survey at 110 sites in four U.S. metropolitan areas—Baltimore, Detroit, Houston, and Los Angeles—using the same methods as in the belt use studies just referenced. Drivers were actually observed in their cars at sites where they slow to less than 15 miles per hour. Model year of vehicles was obtained by recording vehicle license numbers and identifying them in the state motor vehicle administrations.

In 1974 model U.S. cars, all originally equipped with the interlock, only 27 per cent lap and shoulder belt use with an additional 8 per cent lap belt use was found among 5,241 drivers observed. Use in 1975 U.S. cars, some of which were manufactured with the interlock prior to the federal law prohibiting it, was similar to 1974 cars—27 per cent lap and shoulder belt use with an additional 7 per cent lap belt use among 1,611 drivers observed. This means that two-thirds of drivers in 1974 and 1975 cars were unprotected by any restraints in U.S. metropolitan areas.

The evidence strongly suggests that even the low percentage of belt use by drivers in new 1975 U.S. cars is the maximum likely to be achieved. Belt use tends to decline as

TABLE 3—Injuries (Abbreviated Injury Score ≥ 2) By Type of Crash and Belt Use—Towaway Crashes of 1973-75 Model Cars*

	Claimed Belt Use					
	Front and Front Angle Crashes			Side, Rear, and Rollover Crashes		
	Unbelted	Lap Belted	Lap and Shoulder Belted	Unbelted	Lap Belted	Lap and Shoulder Belted
Per Cent Injured	12	10	5	13	7	5
Number of Occupants Involved	3514	964	1456	2544	851	1429

Per Cent Effectiveness of Lap Belt Only $= \frac{12 - 10}{12} = 17\% = \frac{13 - 7}{13} = 46\%$

Per Cent Effectiveness of Lap and Shoulder Belt $= \frac{12 - 5}{12} = 58\% = \frac{13 - 5}{13} = 62\%$

*Source: Table 3, p. 10, in Reference No. 29.

cars get older.[31] Passengers are less likely to use belts than drivers,[32] and children far less so.[33] Belt use in small cities has been found to be considerably less than in metropolitan areas.[34] And the interlock system on some of the 1975 cars will not be on subsequently produced cars. In the Detroit area, where there is presumably a greater proportion of people who knew how to disconnect the interlock, 79 per cent of drivers of 1974 cars and 74 per cent of drivers of 1975 cars were not using any belts.

The study of towaway crashes of 1973–1975 model cars noted earlier[27] also found that claimed belt use varied by crash configuration. Only 25 per cent of occupants in frontal crashes were using lap and shoulder belts compared to 30 per cent of occupants whose vehicles were in side, rear, and rollover crashes. Since more severe injuries occur in frontal crashes, this could mean that false claims of belt use were more prevalent in the less severe nonfrontal crashes. Or it could mean that those more likely to be injured are less likely to use belts. Also, since that study was done during the period of the interlock's peak effect, even lower belt use would be found now.

The 1970 mandatory belt use law enacted in Victoria, Australia initially increased belt use to 75 per cent of passengers in equipped vehicles in metropolitan areas and 64 per cent in rural areas.[8] A decline in vehicle occupant fatalities of 21 per cent in metropolitan areas and 10 per cent in rural areas was found compared to other Australian states without such a law at the time.[35] A similar effect occurred in New South Wales, Australia when such a law was enacted there.[36] Belt use in Ontario, Canada increased similarly to that in Victoria—to 72 per cent in urban areas and 66 per cent in rural areas after the law went in force there in January, 1976. Since speed limits were reduced 10 miles per hour at the same time, effects of the belt law alone will be impossible to separate.[37] Other countries (or political jurisdictions within a few countries) have also enacted belt use laws and some have claimed reduction in fatalities but adequate details of the research methods used are not available.

Despite endorsement of belt laws by belt manufacturers, automobile manufacturers, the federal government, insurers, and others, no U.S. state has enacted a belt use law at this writing. Subsequent to such a law in Puerto Rico belt use rose to 24 per cent. However, the law was weakened in response to public objections and, at last count, belt use was 10 per cent.[38] The Australian experience suggests that substantial immediate reductions in motor vehicle occupant deaths and disabling injuries can be achieved by a belt law. Whether such laws could be enacted and enforced in each of the 50 U.S. states within the current U.S. environment remains problematic.

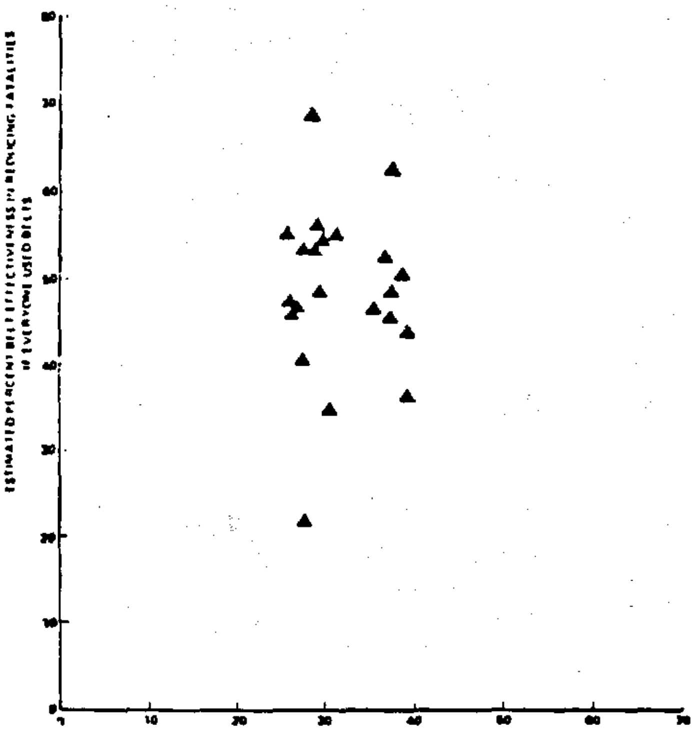

FIGURE 3—Estimated percent effectiveness of belts in reducing fatalities as a function of claimed belt use—yearly data from Arizona (1967–74), Nebraska (1967–74), and Virginia (1969–74)

Implications for Vehicle Occupant Protection

The majority of occupant fatalities occur in front and front-angle crashes. The U.S. Department of Transportation, in 1970, first proposed a requirement for automatic protection for front seat occupants in frontal barrier crashes up to 30 miles per hour for 1973 cars. The proposal was subsequently delayed a number of times but allowed as an option to belts with buzzer-light systems and, later, ignition-interlock systems. A decision to require the automatic systems on all vehicles[39] is pending at this writing. Lap belts would also be required unless standards for protection in side impacts and rollovers were met.

Opponents of the requirement have based their objections on claims that belts obtain similar benefits at less cost. Uncertainties as to exact effectiveness of belts, uncertainty regarding anticipated usage of belts, and arguments over actual costs and what the public will be charged for automatic systems, singly or in combination, have been used in attempts to further delay the decision.

Despite the uncertainties, the issues are clear. Belts offer substantial protection to vehicle occupants but there are no known means to obtain universal belt use. In the unlikely event that 50 states enact belt laws and belt use reaches 70 per cent or so, large numbers of occupants would remain unprotected in crashes. Automatic protection which requires no action by vehicle users would reduce the severity of injuries to belt users and particularly so to nonusers. The extensive tests of air bags indicate that they provide protection superior to belts alone in forward decelerations.[40] Belts and automatic protection are complementary—not competing—means of increasing occupant crash protection.

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APPENDIX

The data from the 19 studies displayed in Figures 1 and 2 were analyzed using multiple linear regression. Since relative seriousness of injury was related exponentially to estimated effectiveness, the logarithm of per cent estimated effectiveness was expressed as a function of parent claimed belt use and per cent of occupants excluding the most serious injury category.

The multiple regression analysis resulted in the following coefficients and statistical significance tests:

Effect of claimed use = 0.02, $t = 2.34$, $df = 16$, $p = 0.03$

Effect of including less serious injuries = 0.04, $t = 1.51$, $df = 16$, $p = 0.15$

Regression Constant = −0.40

Thus, the effect of including less serious injuries is not statistically significant when the effect of claimed belt use is held constant.