■ 研究論文

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SAFETY BELT EFFECTIVENESS VERSUS CRASH TYPES*

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Abstract

Based on Fatal Accident Reporting System (FARS) data, safety belt effectiveness in preventing fatalities is investigated for the following five types of crashes: frontal, left, rear, right, and rollover. Passenger cars containing two occupants, a driver and a right front passenger, are included in this analysis. For each crash type, these cars containing the two occupants are classified into four categories according to the safety belt usage categories for the two front seat occupants, namely, both belted, both unbelted, and either one was belted but not both. Relative risks of driver and right front passenger fatalities are compared among these four cases. For each crash type, two independent estimates of safety belt effectiveness are obtained for drivers and for right front passengers. The weighted average of the two estimates is calculated for drivers and for right front passengers for the five crash types.

Using FARS data starting 1978 throught 1983, safety belts are more effective in rollover accidents than in frontal collisions. In rollover accidents, safety belt effectiveness estimate for drivers is 68% ± 6% and that for right front passengers is 71% ± 6%, in which the error limits indicate one standard error. Safety belt effectiveness estimates for drivers and right front passengers involved in frontal collisions are 41% ± 9% and 37% ± 10%, respectively. For left and right sided collisions and for both drivers and right-front-passengers, none of the four estimates are significantly different from 0%, statistically; however, when left and right sided collisions are combined with far sided occupants(drivers involved in right sided collisions and right front passengers involved in left sided collisions) safety belt effectiveness is significant, 38% ± 12%. For rear collisions, the estimate for drivers shows statistically significant positive effect, 60% ± 23%, while for right-

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front-passengers the estimate is not significantly different from 0%. These results show that a safety belt is an effective restraint system not only in frontal crashes but also in a variety of crashes.

Introduction

This study examines safety belt effectiveness based on Fatal Accident Reporting System (FARS) data. The subject, safety belt effectiveness, has been of continuing interest to the automotive safety community; however, relatively little attention has been paid to FARS data for the purpose of obtaining safety belt effectiveness. For example, a recent study on safety belt effectiveness by the National Highway Traffic Safety Administration (NHTSA) did not use FARS data for the purpose of obtaining effectiveness (1984).

A basic difficulty using FARS data in studying safety belt effectiveness is that occupants who survived due to safety belts are not recorded in FARS if they were involved in non-fatal accidents. In this study, passenger cars with a driver and a right front passenger are used to study the effectiveness of safety belts in terms of saving lives. For a restraint system to be effective, it should offer restraint for a variety of crashes (Wilson and Savage, 1973). Hence, this study examines effectiveness according to five types of crashes - frontal, left, right, rear and rollover - since the occupant and vehicle kinematics during impact might affect effectiveness.

Data

The data base for this study is the 6-year accumulation of fatal motor vehicle traffic accidents from 1978 through 1983 recorded in FARS (NHTSA, 1981). Only the passenger cars which had both a driver and a right front passenger were selected among all cars reported to have two occupants. Occupants who were 16 years or older are included in this study. Passenger cars of model year 1974, or later, are utilized in the analyses; 1974 was the first model year for which manufacturers were required to equip all cars with integrated three-point lap and shoulder belts for driver and right front passenger seating positions. Cars of model year earlier than 1974 are not used because of apparent coding errors in the variable which indicates the type of restraint used in FARS (Evans, 1986b). All drivers and right front passengers in cars of model year 1974 or later coded as using any type of restraint are assumed to have used lap and shoulder belts. The analyses were confined to cars in which both driver and right front passenger had a known restraint status - belted or not belted.

Principal damage area and rollover information was used to classify the types of crashes. Since the recording of rollover information started in 1978, the data from FARS befor 1978 is not used in the analyses. In detail, a car crash was classified as rollover if rollover occurred as the first or subsequent event. For a non-rollover crash, principal impact point (position of the impact that produces the greatest personal injury or property damage) was used to categorize a crash as

frontal if the impact point was recorded in FARS as 12 o'clock;
left if the impact point was recorded in FARS as 9 o'clock;
right if the impact point was recorded in FARS as 3 o'clock; and
rear if the impact point was recorded in FARS as 6 o'clock.

This study is not restricted to the occupants who remained in the cars, i. e. ejected or partially ejected occupants were included. Since wearing a safety belt prevents an occupant from being ejected, it is appropriate to include such cases.

Estimation

Due to the symmetry of the situation, safety belt effectiveness for drivers involved in frontal collisions are considered to explain the method. The effectiveness for right front passengers (RFP) can be obtained, similarly. To estimate the safety belt effectiveness for drivers involved in frontal collisions, we need an estimate of the following:

$$R = \frac{\text{Probability of fatalities to belted drivers}}{\text{Probability of fatalities to unbelted drivers}} \quad (1)$$

An estimate of safety belt effectiveness, E, can then be obtained by

$$E = (1-\hat{R}) \cdot 100\% \quad (2)$$

where $\hat{R}$ is an estimate of R.

All passenger car crashes classified as frontal collisions are categorized into the following four cases based on the safety belt usage categories for the two front seat occupants. The four cases are:

a) both driver and right front passenger were not belted;
b) both driver and right front passenger were belted;
c) a driver was belted and a right front passenger was not belted; and
d) a driver was not belted and a right front passenger was belted.

From these four cases, two estimates of R, R_1 and R_2, will be obtained: R_1 is based on cases a) and c) (in both cases, right front passengers were not belted), and R_2 is based on cases b) and d) (in both cases, right front passengers were belted).

Table 1 provides the data for the above four cases and are to be interpreted as follows. In the case of both occupants being unbelted, table a) of

Table 1, there were 1624 crashes in which right front passengers were fatal while drivers were not; and in contrast, there were 1511 crashes in which drivers were fatal and right front passengers were not. And there were 1026 crashes in which fatalities occurred to both drivers and right front passengers. The number of crashes in which both occupants survived is not given since the number of such crashes resulted from non-fatal accidents can not be retrieved from FARS data; hence the total number of crashes occurred is not known for any of the above four cases, a), b), c), and d).

For crashes with belted drivers and unbelted right front passengers, case c), there were 35 (= 21+14) belted driver fatalities and 63 (= 49+14) unbelted right front passenger fatalities. Since belted driver fatalities are known for case c) crashes, namely 35, an estimate of unbelted driver fatalities, N_1, for case c) crashes is sufficient to estimate safety belt effectiveness. Since case a) is for both unbelted occupants, an estimate of unbelted driver fatalities can be obtained by rescaling case a) so that, the number of unbelted right front passenger fatalities for this case is 63. In other words, all entries in table a) were multiplied by the following ratio:

$$\frac{\text{number of unbelted RFP fatalities from case c)}}{\text{number of unbelted RFP fatalities from case a)}}$$

$$= \frac{63}{1624+1026} = \frac{63}{2650}$$

Table 1. Frontal collsions.

a) Both Unbelted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	1624
Fatal	1511	1026

b) Both Belted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	62
Fatal	54	27

c) Driver - Belted
RFP - Unbelted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	49
Fatal	21	14

d) Driver - Unbelted
RFP - Belted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	17
Fatal	29	8

The results from the rescaling are shown below.

a) Both Unbelted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	1624
Fatal	1511	1026

a′) Both Unbelted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	38.61
Fatal	35.92	24.39

Note that number of unbelted right front passenger 'fatalities' in table a′) is 63 (=38.61+24.39). Hence, the estimate of unbelted driver fatalities for case c), N_1, is

$$N_1 = 35.92 + 24.39 = 60.31$$

Since the number of case c) crashes is common to both numerator and denominator, R_1, an estimate of R from cases a) and c) where right front passengers were unbelted in both cases, is

$$R_1 = \frac{\text{number of belted driver fatalities}}{N_1}$$

$$= \frac{35}{60.31} = 0.58$$

with a variance $\sigma_1^2 = 0.0108$. Using the equation (2), E_1, an estimate of safety belt effectiveness for drivers involved in frontal collisions, is

E_1 = 42% with a standard error of 10% (= 100% · σ_1) which is denoted as
= 42% ± 10%.

Similarly, E_2, another estimate of safety belt effectiveness, will be obtained based on cases b) and d). There were 37 (=29+8) unbelted driver fatalities and 25 (=17+8) belted right front passenger fatalities for case d) crashes. To estimate the safety belt effectiveness, an estimate of belted driver fatalities, N_2, for case d) crashes is necessary. After rescaling 89 (=62+27) belted right front passenger fatalities for case b) by the number of belted right front passenger fatalities for case d), namely 25,

$$N_2 = (54+27) \cdot \frac{25}{89} = 22.75, \text{ and}$$

$$R_2 = \frac{N_2}{\text{number of unbelted driver fatalities}}$$

$$= \frac{22.75}{37} = 0.61$$

with a variance $\sigma_2^2 = 0.0249$. The corresponding estimate of safety belt effectiveness, E_2, is

E_2 = 39% ± 16% where 16%
= 100% · σ_2.

To combine the two estimates, R_1 and R_2, a weighted average of $\log(R_1)$ and $\log(R_2)$ is used rather than that between R_1 and R_2 because of asymmetry in the distributions of R_1 and R_2. Let ζ_1 and ζ_2 be the standard errors of $\log(R_1)$ and $\log(R_2)$, respectively. The weighted average between $\log(R_1)$ and $\log(R_2)$, W, is

$$W = \frac{\zeta_2^2}{\zeta_1^2+\zeta_2^2} \cdot \log(R_1) + \frac{\zeta_1^2}{\zeta_1^2+\zeta_2^2} \cdot \log(R_2) \qquad (3)$$

with a variance,

$$\sigma^2 = \left(\frac{\zeta_2^2}{\zeta_1^2+\zeta_2^2}\right)^2 \cdot \zeta_1^2 + \left(\frac{\zeta_1^2}{\zeta_1^2+\zeta_2^2}\right)^2 \cdot \zeta_2^2 \qquad (4)$$

The weighted estimate of safety belt effectiveness for drivers involved in frontal collisions is

$$E = \{\, 1-\exp(w) \,\} \cdot 100\% \cdot \text{with a standard error of } 100\% \cdot \exp(w) \cdot \sigma \qquad (5)$$

Now, the logarithms of R_1 and R_2 are log(.58) and log(.61) with variances

$$\zeta_1^2 = \sigma_1^2/R_1^2 = 0.0108/0.58^2 = 0.0322 \text{ and}$$

$$\zeta_2^2 = \sigma_2^2/R_2^2 = 0.0249/0.61^2 = 0.0658,$$

respectively. Using the equations (3) and (4), W, a weighted average between $\log(R_1)$ and $\log(R_2)$ is

$$W = -0.5252 \text{ with a variance } \sigma^2 = 0.0216.$$

Finally, using the equation (5), the weighted estimate of safety belt efectiveness, E, for drivers involved in frontal collision is

$$E = 41\% \pm 9\%.$$

A detailed justification of this method can be found in Appendix Ⅱ in Park (1987). Using FARS data, Evans has also estimated overall safety belt effectiveness disregarding crash types, using the method described above (1986b). An explanation on justification of the method can also be found in Evans (1986a).

Results

Similar calculations as described in the previous Section have been carried out for the other collision types. Table 2 shows the two estimates of safety belt effectiveness for drivers and for right front passengers depending on crash type. For drivers involved in a given crash type, one estimate is based on cases a) and c) with unbelted right front passengers and the other estimate is based on cases b) and d) with belted right front passengers (see Estimation section for cases a), b), c) and d). For right front passengers, one estimate is based on cases a) and d) with unbelted drivers and the other estimate is based on cases b) and c) with belted drivers. Detailed data can be seen in Tables 5 to 8 in Appendix I.

Table 3 shows the weighted average

Table 2. Lap and shoulder safety belt effectiveness for drivers and right front passegers according to crash types.

	Drivers		Right Front Passengers	
	Based On Unbelted RFP	Based On Belted RFP	Based On Unbelted Drivers	Based On Belted Drivers
Frontal	42% ± 10%	39% ± 16%	35% ± 14%	39% ± 13%
Left	29% ± 21%	3% ± 52%	17% ± 42%	39% ± 22%
Right	31% ± 23%	31% ± 26%	24% ± 25%	24% ± 29%
Rear	83% ± 16%	33% ± 48%	-40% ± 73%	64% ± 38%
Rollover	69% ± 7%	66% ± 12%	69% ± 9%	72% ± 8%

of the two estimates for drivers and for right front passengers according to crash type. For right front passengers involved in rear collisions, safety belt effectiveness is estimated to be - 7%. However, the standard error associated with the estimate, 50%, dominates the absolute value of the estimated effectiveness, 7%. In other words, the data is insufficient to provide the true value of effectiveness for this case.

Discussion

Table 3 shows that lap and shoulder belts tend to be more effective in rollover accidents than in frontal collisions; however, the potential fatality reduction by wearing lap and shoulder

Table 3. Lap and shoulder safety belt effectiveness for drivers and right front passengers according to crash types.

	Driver	RFP
Frontal	41% ± 9%	37% ± 10%
Left	24% ± 20%	32% ± 20%
Right	31% ± 17%	24% ± 19%
Rear	60% ± 23%	-7% ± 50%
Rollover	68% ± 6%	71% ± 6%

belts from frontal collisions is greater since frontal collisions occur much more frequently than rollover accidents. Wilson and Savage also reported higher effectiveness from rollover accidents than frontal collisions, although the magnitudes of effectiveness are different (1973). For rear collisions, safety belt shows statistically significant positive effect for drivers, i.e. 95% confidence interval is (15%, 100%).

For left and right sided collisions, nominal estimates of effectiveness for far sided occupants (drivers involved in right sided collisions or right front passengers involved in left sided collisions) is greater than that for near sided occupants in both collisions. However, none of the estimates for side impacts are significantly different from 0%, i.e. no significant effect, statistically (all 95% confidence intervals for the true effectiveness contain 0%).

Safety belt effectiveness for near sided and far sided occupants from side impacts are presented in Table 4. This calculation was made after combining the data from left and right sided collisions, disregarding the difference between the two seating positions (see Table 9 in Appendix I). When the left and right sided collisions are combined, safety belt effectiveness for far sided occupants shows a significant positive effect, i.e. 95% confidence interval (14%, 61%) does not contain 0%. However, the effectiveness for near sided occupants is not significantly different from 0%, statistically (i.e. 95% confidence interval (-4%, 50%) contains 0%).

Table 4. Lap and shoulder belt effectiveness for near and far sided occupants from side impacts (combination of left and right sided collisions).

Near	23% ± 14%
Far	38% ± 12%

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References

Bishop, Y. M. M., Fienberg, S. E. and Holland, P. W., Discrete Multivariate Analysis, The MIT Press, 1975.

Evans, L., Double pair comparison -- a new method to determine how occupant characteristics affect fatality risk in traffic crashes, Accident Analysis and Prevention, 18, 217-227, 1986a.

Evans, L., The effectiveness of safety belts in preventing fatalities, Accident Analysis and prevention, 18, 229-241, 1986b.

National Highway Traffic Safety Administration, Fatal Accident Reporting System, Dept. of Transportation, National Center for Statistics and Analysis, August, 1981.

National Highway Traffic Safety Administration, Final regulatory impact analysis - amendment to FMVSS No. 208, passenger car front seat occupant protection, Plans and Programming office of Planning and Analysis, July 11, 1984.

Park, Weongil, Safety belt. effectieness versus crash types, GMR-5710, General Motors Research Publication, February 2, 1987.

Wilson, R. A. and Savage, C. M., Restraint system effectiveness - a study of fatal accidents, Proceedings of the Automotive Safety Engineering Seminar sponsored by the Automotive Safety Engineering, Environmental Activities Staff, General Motors Corporation, June 20-21, 1973.

Apendix I

Table 5. Left sided collisions.

Both Unbelted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	162
Fatal	868	308

Both Belted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	4
Fatal	42	16

Driver - Belted
RFP - Unbelted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	8
Fatal	18	5

Driver - Unbelted
RFP - Belted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	2
Fatal	10	2

Table 6. Right sided collisions.

Both Unbelted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	1351
Fatal	153	354

Both Belted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	63
Fatal	3	19

Driver - Belted
RFP - Unbelted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	33
Fatal	153	6

Driver - Unbelted
RFP - Belted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	12
Fatal	1	6

Table 7. Rear collision.

Both Unbelted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	92
Fatal	69	51

Both Belted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	8
Fatal	2	2

Driver - Belted
RFP - Unbelted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	6
Fatal	0	1

Driver - Unbelted
RFP - Belted

RFP / Driver	Non-Fatal	Fatal
Non-Fatal	-	3
Fatal	1	2

Table 8. Rollover.

Both Unbelted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	1388
Fatal	1743	511

Both Belted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	27
Fatal	39	11

Driver - Belted
RFP - Unbelted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	62
Fatal	18	8

Driver - Unbelted
RFP - Belted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	11
Fatal	48	2

Table 9. Side collisions(Tables4 and 5 combined).

Both Unbelted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	315
Fatal	2219	662

Both Belted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	7
Fatal	105	35

Driver - Belted
RFP - Unbelted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	9
Fatal	30	11

Driver - Unbelted
RFP - Belted

Driver \ RFP	Non-Fatal	Fatal
Non-Fatal	-	4
Fatal	43	8