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The Influence of Rear-seat Occupants on Front-seat Occupant Fatalities:The Unbelted Case

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Abstract

A possible adverse effect on the likelihood of front-seat occupant fatalities from unbelted rear-seat occupants in frontal crashes is investigated using Fatal Accident Reporting System data. Passenger cars which sustained frontal damage and which did not roll over are included in this analysis. Of the frontally damaged cars, only cars containing a driver and a right-front passenger are selected. Then, from these cars, the following three cases are considered: a) left-rear occupant present, b) right-rear occupant present, and c) no one else in the car. Cars belonging to a) or b) contain only three occupants, and those belonging to the last case contain only two occupants. In addition, all occupants are unbelted.

To estimate the influence of rear-seat occupants on front-seat occupant fatalities, relative risks of driver and right-front passenger fatalities are compared pairwise across these three cases. The adverse influence of unbelted rear-seat occupants on the likelihood of unbelted front-seat occupant fatalities in frontal crashes is estimated to be 7.9% ± 45% (the error limits indicate one standard error). In other words, front-seat occupant fatalities are increased 7.9% in frontal crashes due to the loadings from unbelted rear-seat occupants. This suggests that the usage of safety belts by rear-seat occupants not only may extend their own lives but also helps in reducing the fatalities of front-seat occupants seated in front of them.

1. Introduction

Safety belts are well known as an effective device in reducing car occupant fatalities as well as injuries in crashes(Campbell, 1984; Evans, 1986b; Wilson and Savage, 1973). Research to date has focused priomarily on the direct benefit of wearing safety belts in crashes, namely, lower fatality or injury rates resulting for those occupants who wear safety belts versus those who do not. In this report, we are concerned with an indirect effect of safety belt usage, the influence of unbelted occupants on the likelihood of other occupant fatalities in crashes. Specifically, this study was performed to determine whether the additional loading from unbelted rear-seat occupants has any adverse effect on the likelihood of unbelted

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front-seat occupant fatalities in frontal crashes. If there is an adverse effect, then this would suggest that the usage of safety belts by rear-seat occupants not only may extend their own lives, but also helps in reducing the fatalities of front-seat occupants seated in front of them.

Griffiths et al.(1976) reported the possibility of fatality reduction on restrained front-seat occupants if the rear-seat occupants had been effectively restrained. Based on the laboratory experiments using dummies, Roberts(1983) concluded that the usage of safety belts by rear-seat occupants reduces the risk of injury both to themselves and to other occupants ahead of them in frontal impacts.

2. Data and Method

The data base for this study is the Fatal Accident Reporting System (FARS; National Highway Traffic Safety Administration, 1981). From this data base, only passenger cars which sustained frontal damage (principal impact in the 11, 12 and 1 o'clock areas) and which did not roll over are included in this study. Principal impact point is defined as the impact which produces the greatest personal injury or property damage (National Highway Traffic Safety Administration, 1981). In order to demonstrate the influence of rear-seat occupants on the liklihood of front-seat occupant fatalities, we focus the annalyses on the cars with 12 o'clock impact since the occupant kinematics for this impact are simpler to interpret than those either for the driver-side impact (11 o'clock) or for the passenger-side impact (11 o'clock). Cars with principal impact in the 11 and 1 o'clock areas are used as supplemental information. As rollover information only began to appear in FARS data in 1978, 1978 through 1983 FARS data are utilized.

Of the frontally damaged cars, we selected those containing a driver and a right-front passenger (RFP). Then, from these cars, only the following cases are considered:

a) left-rear occupant present (left-rear occupant case);

b) right-rear occupant present (right-rear occupant case); and

c) no one else in the car (two-occupant case).

Throughout this paper, the cases a), b), and c) are called the left-rear occupant case, the right-rear occupant case, and the two-occupant case, respectively. When the left-rear and right-rear occupant cases are considered together, it is called the three-occupant case.

In order to assess the influence of rear-seat occupants on the likelihood of from-seat occupant fatalities,

R=(probability of drive fatalities)/(probability of RFP fatalities),

is used as a measure of relative risk of fatalities between drviers and right-front passengers (Evans, 1986a; Evans, 1986b). For each of the cases considered above, the ratio of these two probabilities can be estimated even though neither the probability of driver fatalities nor the probability of right-front passenger fatalities is estimable separately, using FARS data. Since FARS is the census of fatal accidents, the number of car crashes in which at least one occupant was killed can be obtained; however, the number of crashes in which all occupants survived the accident is not known since non-fatal accidents are not recorded in FARS data. Hence, the total number of crashes for any of the above three cases is not known. However, for each of the cases considered, the total number of the fatalities is known. Therefore, the relative risk R is estimated by

R = (number of driver fatalities)/(number of RFP fatalities).

Due to the small sample size of belted occupants, the analyses are confined to cars in which none of the occupants was belted. And, only occupants who were 16 years or older are included in this sutdy since a small child in rear-seat may not have an appreciable influence on the likelihood of front-seat occupant fatalities in frontal crashes.

3. Results

Demonstration Of The Adverse Effect

Relative risk of driver and right-front passenger fatalities for the left-rear occupant case and that for the right-rear occupant case are compared. If the presence of rear-seat occupants has an adverse effect on the likelihood of front-seat occupant fatalities, we expect the relative risk for the left-rear occupant case will be higher than that for the right-rear occupant case.

Next, the left-rear occupant case and the right-rear occupant case are divided into two categories each. They are:

i) crashes in which left-rear occupants were killed;

ii) crashes in which left-rear occupants survived;

iii) crashes in which right-rear occupants were killed; and

iv) crashes in which right-rear occupants survived.

Two comparisons, one between the categories i) and iii), and the other between the categories ii) and iv), are made. The reason why such comparisons are made is as follows. If the presence of rear-seat occupants does have an adverse effect on the likelihood of front-seat occupant fatalities, the effect should be manifested more when the crash is severe. However, stratification of the data by impact severities, the usual method, is not carried out since it is difficult to deduce impact severities from FARS data. As it is natural to expect the chances of a rear-seat occupant being killed to be higher in a severe impact and lower in a less severe impact, the crashes in which rear-seat occupants were fatally injured would, in general, be more severe crashes than those in which rear-seat occupants survived. In other words, by dividing either case according to the fate of a rear-seat occupant, fatally injured or not, both the left-rear and the right-rear occupant cases are separated out into “severe” and “less severe” crashes. Then, two comparisons of relative risks, one for the severe crashes and the other for the less severe crashes, are made.

The relative risks of driver and right-front passenger fatalities for the left-rear and the right-rear occupant cases are compared with the relative risk for the two-occupant case. We expect the relative risk for the left-rear occupant case to be higher than that for thr two-occupant case, and the relative risk for the right-rear occupant case to be lower than that for the two-occupant case.

The Three-Occupant Case.

Data for the three-occupant case, including both the left-rear and right-rear occupant cases with principal impact in the 12 o'clock area, are displayed in Table 1 which is to be interpreted as follows. For example, there were 99 crashes in which both a driver and a left-rear occupant survived and a right-front passenger was fatally injured; and, there were 222 crashes in which both a driver and a right-rear occupant survived and a right-front passenger was killed. The number of crashes in which all three occupants survived is not given since non-fatal accidents are not recorded in FARS data.

〈Table 1〉 The left-rear and right-rear occupant cases for crashes in which principal impact was in the 12 o'clock area.

Driver	RFP	Left-Rear Occupant	No. of Crashes	Driver	RFP	Right-Rear Occuapnt	No. of Crashes
S	S	S	–	S	S	S	–
S	F	S	99	S	F	S	222
F	S	S	85	F	S	S	198
F	F	S	29	F	F	S	64
S	S	F	50	S	S	F	69
S	F	F	19	S	F	F	67
F	S	F	28	F	S	F	27
F	F	F	28	F	F	F	94

S : Survival; F : Fatal

Let R_1 and R_2 be the estimates of reltive risk between driver and right-front passenger fatalities for the left-rear occupant case and for the right-rear occupant case, respectively. Using the data from Table 1,

$R_1=(85+29+28+28)/(99+29+19+28)$

$=170/175=0.97\pm0.09$;and

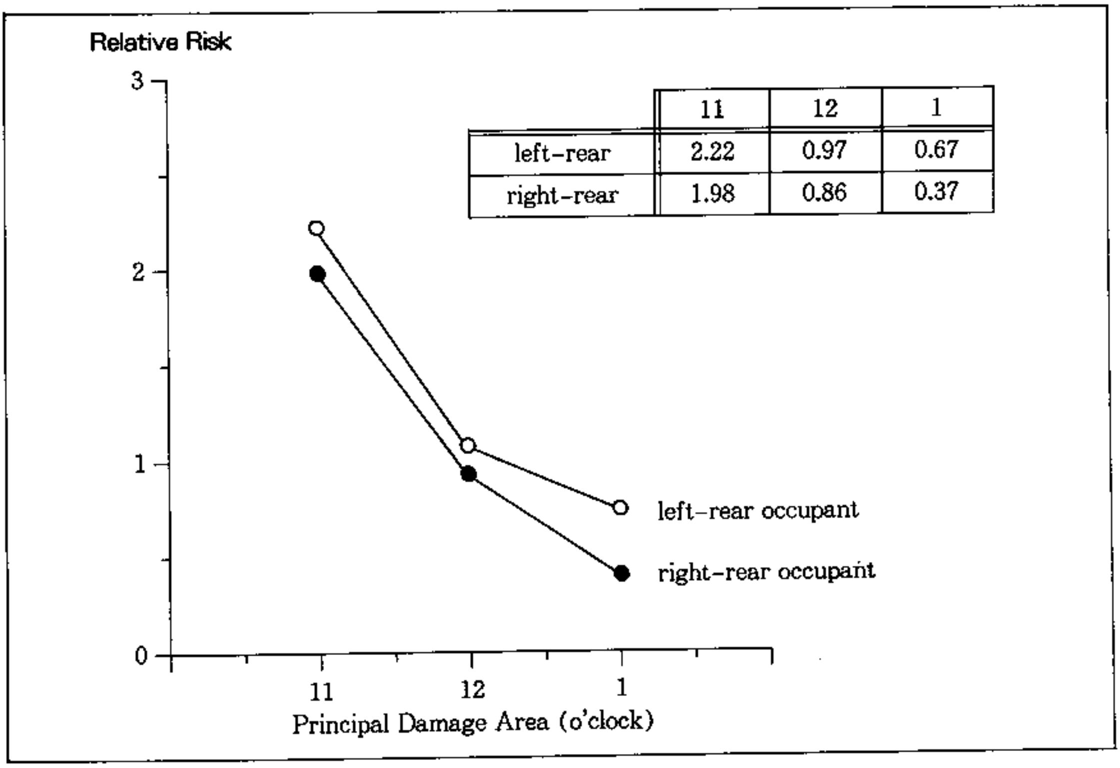
$R_2=(198+64+27+94)/(222+64+67+94)$

$=383/447=0.86\pm0.05$

in which the error limites indicate one standard error. In comparison with $R_2=0.86$, $R_1=0.97$ indicates that there were more driver fatalities when left-rear occupants were present. Likewise, $R_2=0.86$, compared with $R_1=0.97$, indicates that there were more right-front passenger deaths when right-rear occupants were present. Hovever, R_1 is not significantly higher than R_2, statistcally (p-value: 0.11).

Figure 1 shows the relative risk of driver and right-front passenger fatalities between the left-rear and the right-rear occupant cases for crashes with principal impact in the 11 and 1 o' clock areas as well as for those with principal impact in the 12 o'clock area.

Relative risks for crashes with principal impact in the 11 and 1 o'clock areas show a similar trend, namely, there were more driver deaths when left-rear occupants were present and more passenger deaths when right-rear occupants were present. And, they also show that, for either the left-rear or the right-rear occupant case, dirvers are killed more often when the impact is on the driver side, 11 o'clock; and right-front pasengers are killed more often when the impact is on the passenger side, 1o'clock.



	11	12	1
left-rear	2.22	0.97	0.67
right-rear	1.98	0.86	0.37

[Figure 1] Relative risk of driver and right-front passenger fatalities for the left-rear and righ-rear occupant cases with principal impact in the 11, 12, and 1o'clock areas.

Severe And Less Severe Crash Effects.

Let RS_1 and RS_2 be the estimates of relative risk between driver and right-front passenger fatalities for crashes in which left-rear occupants survived, and for those in which right-rear occupants survived, respectively. Then, for the less severe crashes,

$$RS_1 = (85+29)/(99+29) = 114/128 = 0.89 \pm 0.10; \text{and}$$

$$RS_2 = (198+64)/(222+64) = 262/286 = 0.92 \pm 0.07,$$

using the data from the upper half of Table 1. This difference is not statistically significant(p-value:0.58).

Similary, if we let RF_1 be the estimate of relative risk for crashes in which left-rear occupants were killed, and RF_2 be that for crashes in which right-rear occupants were killed, then, for the severe crashes,

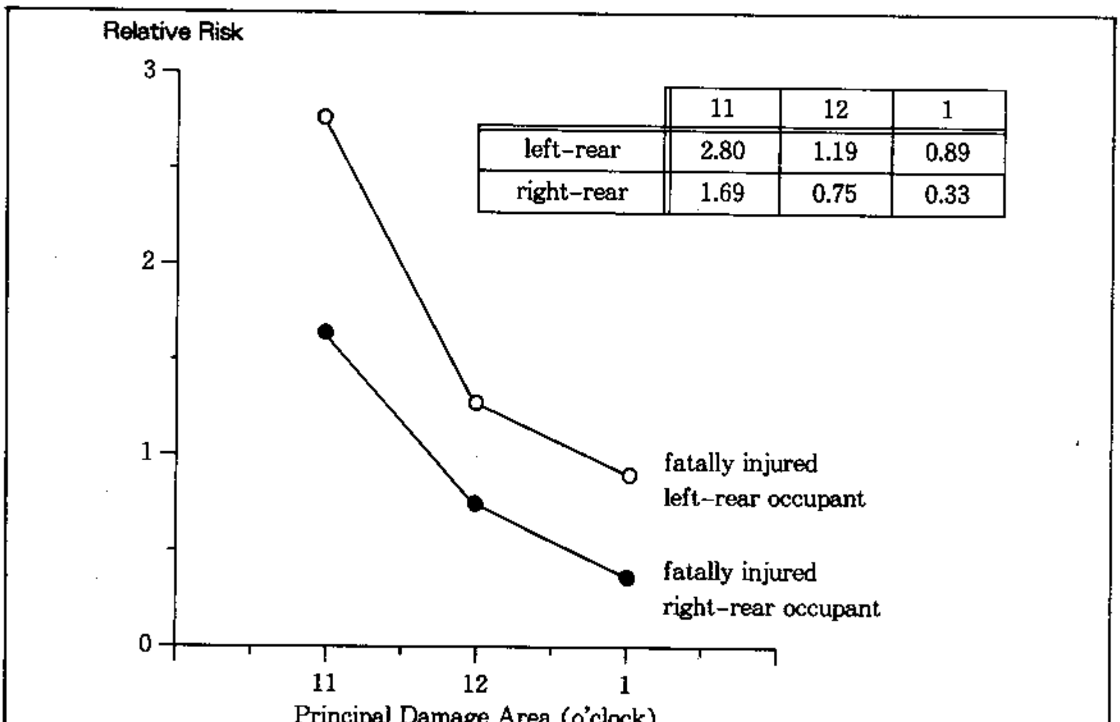
$$RF_1 = (28+28)/(19+28) = 56/47 = 1.19 \pm 0.16; \text{and}$$

$$RF_2 = (27+94)/(67+94) = 121/161 = 0.75 \pm 0.05,$$

using the data from the bottom half of Table 1.

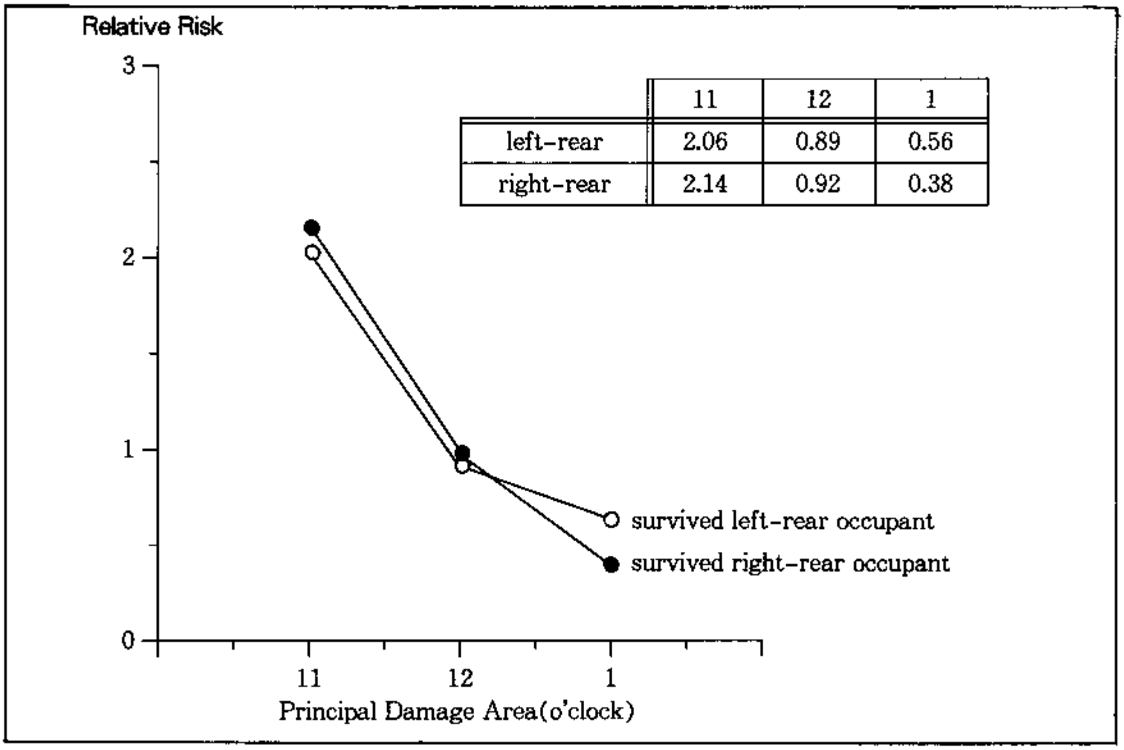
Without the influence of rear-seat occupants on the likelihood of front-seat occupant fatalities, we would expect the relative risk of driver and right-front passenger fatalities to approach 1 as crashes become severe. In other words, any differential effect between driver and right-front passenger fatalities due to the difference in seating positions and occupant characteristics, as well as relative engine compartment position, would disappear as crashes become more servere. However, for the severe crashes, the estimate of relative risk for crashes in which left-rear occupants were killed (RF_1=1.19), is higher than 1. And, the estimate of reltive risk for crashes in which right-rear occupants were killed (RF_2=0.75), is substantially lower than 1. This indicates the adverse influence of rear-seat occupants on the fatality likelihood of occupants seated in front of them. A statistical test also shows that RF_1 is significantly higher than RF_2, statistiically (p-value:0.001).

For the left-occupant case, RF_1(1.19) is significantly higher than RS_1(0.89), statistically (p-value:0.05). However, the difference due to the presence of left-rear occupants may be



	11	12	1
left-rear	2.80	1.19	0.89
right-rear	1.69	0.75	0.33

[Figure 2] Relative risk of driver and right-front passenger fatalities for crashes with principal impact in the 11, 12 and 1 o'clock areas smaller if we assume that the relative risk for the severe crashes without the influence of left-rear occupants is higher than RS_1, 0.89. In other words, the difference between 1.19 and 0.89 may not be used entirely to explain the influence of left-rear occupants on driver fatalities. For the right-rear occupant case, RF_2(0.75) is significantly lower than RS_2(0.92), statistically (p-value:0.03). In this case, the difference due to the presence of right-rear occupants may be larger if we condsider that the relative risk for the severe crashes without the influence of right-rear occupants is higher than RS_2, 0.92.



	11	12	1
left-rear	2.06	0.89	0.56
right-rear	2.14	0.92	0.38

[Figure 3] Relative risk of driver and right-front passenger fatalities for crashes with principal impact in the 11, 12, and 1 o'clock areas for the following two cases: crashes in which left-rear occupants survived and those in which right-rear occupants survived.

Relative risks for crashes in which rear-seat occupants were fatally injured and those for crashes in which rear-seat occupants survived are displayed in Figures 2 and 3, respectively. Trends shown in Figures 2 and 3 are similar to those for crashes with principal impact in the 12 o'clock area.

The Three-Occupant Case versus The Two-Occupant Case.

Table 2 shows the data for the two-occupant case with principal impact in the 12 o'clock area and is to be interpreted as follows. There were 3089 crashes in which right-front passengers wrer killed while drivers were not; and there were 2722 crashes in which drivers were killed while right-front passengers were not. There were 1755 crashes of fatalities to both occupants. As in table 1, the number of crashes in which both occupants survived is not given since non-fatal accidents are not recorded in FARS data. The estimate of relative risk between driver and right-front passenger fatalities for the two-occupant case, R_0, is

$$R_0=(2722+1755)/(3089+1755)$$
$$=4477/4844=0.92\pm0.02.$$

Table 3 shows the estimates of relative risk between driver and right-front passenger fatalities for the three-occupant case as well as that for the two-occupant case.

〈Table 2〉 The two-occupant case for crashes with princiapl impact in the 12 o' clock area.

Driver	RFP	No. of Crashes
S	S	–
S	F	3089
F	S	2722
F	F	1755

S : Survival; F : Fatal

〈Talbe 3〉 Relative risks for the two-occupant and the three-occupant cases for crashes with principal impact in the 12 o'clock area.

Left-rear Occupant Case	Two-occupant Case	Right-Rear Occupant Case
$R_1=0.97$	$R_0=0.92$	$R_2=0.86$

In comparison with $R_0=0.92$, $R_1=0.97$ indicates that there were more driver fatalities when left-rear occupants were present. Similarly, $R_2=0.86$, compared to $R_0=0.92$, indicates that there were more right-front passenger deaths when right-rear occupants were present. In these comparisons, the data consistently suggest that the presence of rear-seat occupants tends to have an adverse effect on the likelihood of front-seat occupant fatalities.

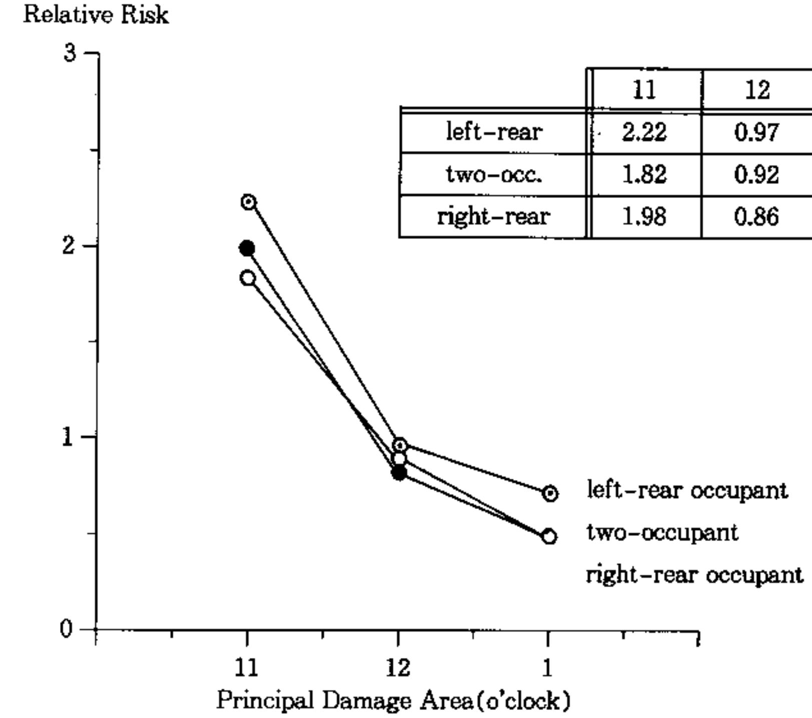
We also tested to see whether the relative risks are different; however, the difference between the relative risks for the left-rear occupant case and for the two-occupant case is not statistically significant(p-value : 0.29), and the difference between the relative risks for the right-rear occupant case and for the two-occupant case is statistically significant(p-value : 0.09).

The relative risks for the two-occupant case with principal impact in the 11, 12, and 1o'clock areas as well as those for the three-occupant case from Figure 1 are dispalyed in Figure 4.

The trend between the two-occupant and the left-rear occupant cases is clearer than that between the two-occupant and the right-rear occupant cases.

Estimation Of The Adverse Effect For Frontal And For All Crashes

The adverse influence of rear-seat occupants on the likelihood of front-seat occupant fatalities has been demonstrated using mainly the crashes with principal impact in the 12 o'clock area. In this section, the adverse influence of rear-seat occupants in frontal crashes is estimated using the crashes with principal impact in the 11 and 1 o'clock area as well as



	11	12	1
left-rear	2.22	0.97	0.67
two-occ.	1.82	0.92	0.37
right-rear	1.98	0.86	0.37

[Figure 4] Relative risk of driver and right-front passenger fatalities for the two-occupant, the left-rear occupant, and the right-rear occupant cases with principal impact in the 11, 12, and 1 o'clock areas.

those with principal impact in the 12 o'clock area. With the assumption of no effect in non-frontal crashes, the adverse effect for all crashes is also estimated.

The following explains how to estimate the influence of rear-seat occupants on the likelibhood of front-seat occupant fatalities. Let R_1 and R_2 be the relative risk of driver and right-front passenger fatalities for the left-rear and for the right-rear occupant cases, respectively. And, let R be the relative risk of driver and right-front passenger fatalities without the influence of left-rear occupants. Then, the increased front-seat occupant (driver) fatalities due to left-rear occupants, $100\varepsilon\%$, can be estimated using, the following relationship:

$R_1 = R(1+\varepsilon)$, which is equivalent to $\varepsilon = (R_1/R) - 1$

For example, R_1 greater than R implies ε is positive, i.e. an adverse influence of left-rear occupants on the likelihood of driver fatalities. For the right-rear occupant case, if we let the same R denote the relative risk of driver and right-front passenger fatalities without the influence of right-rear occupants, then, by symmetry, the increased front-seat occupant(right-front passenger) fatalities due to right-rear occupants, $100\varepsilon\%$, can be estimated using,

$1/R_2 = (1/R)(1+\varepsilon)$, which is equivalent to $\varepsilon = (R/R_2) - 1$

Note that the same quantity ε is ued to measure the effect on both driver and right-front passenger fatalities, i.e. front-seat occupant fatalities. To estimte ε, we use the following two methods, one with R unknown and the other by replacing R with a natural candidate, the relative risk for the two-occupant case. Using the above equations, the two methods for estimating ε are :

method i) $\varepsilon=\sqrt{R_1/R_2}-1$which can be obtained by replacing R of
$R_1=R(1+\varepsilon)$ with
$R=R_2(1+\varepsilon)$; and

method ii) weighted average between $\varepsilon=(R_1/R)-1$ and $\varepsilon=(P/R_2)-1$ after replacing R with the relative risk for the occupant case.

The estimation is carried out using the data for each of the four cases used previously, i.e.,

i) three-occupant case,
ii) severe crashes,
iii) less severe crashes, and
iv) three-occupant and two-occupant cases.

Tbale 4 shows the estimated effect on the likelihood of front-seat occupant fatalities for each of these four cases with principal impact in the 11, 12, and 1 o'clock areas, respectively. And, for each case, it provides the estimate for frontal crashes, the weighted average among the three estimates. The estimates for the crashes with principal impact in the 11 and 1 o'clock areas are obtained with an interest in obtaining the estimates of overall frontal effect rather than an intrinsic interest in themselves.

〈Talbe 4.〉Estimates of effect on the likelihood of front-seat occupant fatalites due to the additional loading from unbelted rear-seat occupants for crashes with principal impact in the 11, 12, and 1 o'clock areas for each of the following four cases : i) three-occupant case, ii) severe crashes, iii) less severe crashes, and iv) three-and two-occupant cases. For each of the four cases, weighted average among the three estimates for frontal crashes, is also provided.

	11 o'clock	12 o'clock	1 o'clock	weighted
Three-Occupant Case	5.9% ±14.1%	6.5% ±5.5%	34.4% ±20.1%	8.8% ±5.0%
Severe Crashes	28.8% ±27.9%	25.9% ±9.5%	63.3% ±33.0%	29.9% ±8.7%
Less Severe Crashes	−1.9% ±16.4%	−1.4% ±6.7%	20.4% ±25.1%	0.2% ±6.0%
Three-and Two-Occupart Cases	1.3% ±12.7%	7.0% ±5.0%	26.5% ±18.5%	7.9% ±4.5%

The method i) is used to calculate the estimates for the cases i), ii), and iii). And, the method ii) is used to calculate the estimates for the case iv). Note that only the method i) is used for the severe and less severe crashes since a natural candidates for the relative risk without the influence of rear-seat occupants does not exist for either of these two cases.

For the severe crashes with impact in the 12 o'clock area, 25.9% ±9.5% more front-seat occupants were killed due to the adverse influence of rear-seat occpants. For the less severe crashes, the influence of rear-seat occupants is not statistically significantly different from 0%, i.e.

no effect. For all crashes with impact in the 12 o'clock area, we decided to use the estimate using the data for the three-occupant and two-occupant cases as the estimate for the adverse effect since more information has been used for this case compared to the estimate using only the data for the three-occupant case. The estimete is 7.0% ± 5.0% which is significantly higher than 0%, statistically(p-value : 0.08).

After combining the estimated effect using the data for the three-occupant and two-occupant cases, we conclude 7.9% ± 4.5%(p-value : 0.04) more unbelted front-seat occupants were killed in frontal crashes due to the additional loading from unbelted rear-seat occupants. For the severe frontal crashes, substantially more front-seat occupants, 29.9% ± 8.7% were killed.

To calculate the adverse effect for all crashes, it is not unreasonable to assume no effect for non-frontal crashes, i.e. 0% ± 0%. Since fatal frontal crashes were about 50% of all passenger car crashes (National Highway Traffic Safety Administration, 1984), the overall adverse effect is estimated to be 3.9% (0.5 times 7.86%) with 2.3% standard error(0.5 times 4.5 %) which is also statistically significant (p-value : 0.04).

4. Summary and Conclusion

Many different comparisons of relative risk between driver and right-front passenger fatalities have been made using the three-occupant and two-occupant cases data. Since the occupant kinematics for the crashes with 12 o'clock impact are simpler to interpret, mainly these crashes are used to demonstrate the adverse influence of rear-seat occupants on the likelihood of front-seat occupant fatalities.

The relative risk for the left-rear occupant case is higher than that for the right-rear occupant case. An effort has been made to separate the left-rear and the right-rear occupant cases into the severe and less severe crashes according to the fate of a rear-seat occupant, killed or not killed. The relative risk for crashes in which left-rear occupants wrer fatally injured is substantially higher than the relative risk for those in which right-rear occupants were killed. In other words, for the severe crashes, unbelted rear-seat occupants have a significant influence on the likelihood of front-seat occupant fatalities. In contrast, relative risks between the crashes in which left-rear occupants survived and those in which right-rear occupants survived are similar, i.e. no appreciable effect for the less severe crashes.

In addition, the relative risks for the left-rear and right-rear occupant cases are compared with the relative risk for the two-occupant case. The relative risk for the left-rear occupant case is higher than that for the two-occupant case; and, the relative risk for the right-rear occupant case is lower than that for the two-occupant case.

After having demonstrated the adverse influence of rear-seat occupants on the likelihood of front-seat occupant fatalities, the adverse effect for frontal crashes has been estimated using the data for the crashes with principal impact in the 11 and 1 o'clock areas as well as those for the crashes with principal impacts in the 12 o'clock area. Combining the estimated effect using the data for the three-occupant and two-occupant cases, the adverse effect due to the additional loading is estimated to be 7.9%±4.5% for frontal crashes. For the severe frontal crashes, the effect is 29.9%±8.7%. After assuming no effect for non-frontal crashes, the overall adverse effect for all crashes is estimated to be 3.9%±2.3%.

Mackay(1985) reported that about 6% of correctly restrained front-seat occupants in vehicles with rear-seat occupants were killed by being loaded from behind by unconstrained rear-seat occupants(Transport Committee, 1985). The overall adverse effect 3.9% is in good agreement with 6% reported although this 6% is on restraained fron-seat occupant fatalities.

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