EJECTION and AUTOMOBILE FATALITIES

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PRIOR to the advent of studies of injuries sustained in automobile crashes, the belief was prevalent that being "thrown clear" of the car during an accident would generally save one's life. As the Automotive Crash Injury Research project of Cornell University Medical College accumulated case histories from the reports of trained police and highway patrol investigators, however, it became clear that this supposition was contrary to the evidence.

The present study uses data from these reports to answer two initial questions: Is the risk of fatal injury greater for those ejected from automobiles in an accident than for those who remain inside? What fatality would be expected for those ejected had they remained inside the cars?

Answers to these questions are applied to data on national fatality figures in order to answer a third question, which is the principal objective of this study: If ejection increases the risk of fatality, what is the estimated number of lives that could be saved annually by preventing ejection in injury-producing accidents?

The present study is an extension of an earlier one in which it was observed that ejection from an automobile under crash impact conditions was associated with a double risk of moderate through fatal injuries (*1*). Both the previous and present studies represent portions of the large-scale investigation of injuries in automobile crashes conducted at Cornell University Medical College. The general plan and organization of this investigation have been described in previous reports (*1–4*).

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Materials

Detailed accident-injury reports, containing comprehensive information on 3,261 passenger automobiles and their 7,337 occupants, were collected and analyzed and subsequently coded and transferred to punchcards.

All of these accidents had resulted in injury of some kind to at least one of the occupants involved. The accidents ranged in severity from minor to extreme, and the injuries ranged in degree from trivial to fatal.

All common makes and models of American automobiles manufactured prior to 1956 and operated during the sampling period (beginning of 1953 through May 1956) were represented. Those manufactured after 1956 were excluded because many manufacturers improved their door locks in that year. Doors equipped with these new lock mechanisms have been demonstrated to open less frequently under crash impact conditions and to be associated with a decrease in the frequency of ejection (*2*).

The data were collected at the accident scene in 14 States and 1 city: Arizona, California, Colorado, Connecticut, Indiana, Maryland, Michigan, Minnesota, New York, North Carolina, Pennsylvania, Texas, Vermont, Virginia, and Minneapolis. The States provide the sample with rural accidents; the city, with urban accidents.

In each participating area, police or highway patrolmen in preselected geographic districts completed special report forms and submitted detailed photographs for each injury-producing accident. Examining physicians supplied precise medical information on each injured person. History, data sources, and general methods of the Automotive Crash Injury Research project have been previously outlined (*3*, *4*).

These accidents are believed to be representative of typical crashes in which persons were injured (*3*).

Another source of material was the national motor vehicle fatality figures gathered by the National Office of Vital Statistics and reproduced by the statistics division of the National Safety Council (*5*). Such data are published annually in Accident Facts, where tabulations of accidental deaths and injuries from many sources are collected and classified under gross cause headings.

Definitions

Accident severity: Total decelerative forces and overall structural damage produced by the accident, described in five grades: (1) minor; (2) moderate; (3) moderately severe; (4) severe; and (5) extremely severe and extreme. These terms do not describe the injury effects of the accident, but only the forces and structural damage conditions.

Complete ejection: Complete ejection through a door that has "popped open" as a result of impact against some portion of the car other than the door in question. Occupants defined as completely ejected must be outside the car before sustaining their principal injuries. Doors opened by direct impact to the doors themselves are not classified as open in studies concerned with ejection since occupants adjacent to these doors are quite likely to have been seriously injured prior to leaving the car.

Seated position: The position determined by where an occupant might sit: driver, right front, center rear, and so on.

Serious and critical injuries: Injuries which, because of their nature and severity, are potentially or actually dangerous to life.

Methodology

Of all the passenger car occupants who were fatally injured, a distinction was made between those whose injuries resulted from contact with structures inside the car and those whose injuries were the direct consequence of complete ejection from the car, that is, the injuries were sustained outside the car. The 2 frequencies of fatal injury result in 2 different risks of fatality.

The following hypothesis was adopted to determine the expected risk of fatal injury for those ejected had they remained inside the car, with the other circumstances remaining unchanged. It was postulated that had the occupants not been ejected, their risk of fatality would have been equivalent to the observed risk among persons who actually remained inside the car, in corresponding seats, and under the same force conditions. Pursuing this hypothesis, data were first arranged to show the observed risk of fatality for nonejected occupants in each category of seated position and accident severity. The expected number of fatalities among persons ejected from corresponding seated positions and in accidents of comparable severity could then be obtained by using the method of observation and expectancy.

Pursuing the original hypothesis further, the expected number of fatalities among occupants of all seats and in accidents of all severities, assuming that none had been ejected, was then compared with the observed number of fatalities to establish the proportion that would have been avoided in the sample if ejection had been controlled. The proportion thus obtained, when applied to national fatality figures, provides an estimate of the number of lives that could have been saved by preventing ejection.

Fatality Risks in Ejection

Among the 7,337 occupants of passenger automobiles involved in any type of injury-producing accident, 13.6 percent were completely ejected, and 81.6 percent remained inside the car. Information on the remaining 4.8 percent of the occupants was doubtful, and these were eliminated from the study.

In table 1, persons completely ejected are compared with persons who definitely remained inside the car, and the proportion of fatally injured persons in the two groups is shown, thus providing an answer to the question: Is the risk of fatal injury greater for ejected persons than for those who remain inside the car?

There were 9.6 percent fewer fatalities among those not ejected than among those ejected ($P<.001$). Further, the risk of fatality among the ejected was demonstrated to have been nearly five times as great as that among those not ejected: 12.1 percent for those ejected versus 2.5 percent for those not ejected. These data clearly suggest that the number of fatalities in automobile accidents would be reduced by minimizing the occurrence of ejection.

The material which follows deals with the methodology and rationale employed in predicting the number of lives that would have been saved in the sample if those ejected had not been ejected. This methodology must, of course, take into account the fact that a certain number of persons, even if they had remained inside the car, would nevertheless have been exposed to some risk of fatal injury; that is, at least the 2.5 percent risk experienced by those not ejected. Thus it must by no means be assumed that the 5 to 1 ratio seen in table 1 implies an 80 percent reduction in the total number of fatalities if ejection is eliminated. Furthermore, it also cannot be assumed that the occurrence of fatality is related exclusively to the occurrence of ejection or nonejection. Other accident-injury factors must be taken into account.

Table 1. Risks of fatal injury for those ejected and those not ejected

	Not fatally injured	Fatally injured	Total	Percent fatally injured
Ejected	876	121	997	12. 1
Not ejected	5, 843	147	5, 990	2. 5
Total	6, 719	268	[1] 6, 987	3. 8

[1] Data on 350 of the 7,337 occupants studied have been omitted since details on ejection were not completely reported for these persons.

Accident Severity, Seats, and Fatality

As has been indicated in table 1, the risk of fatality was greatly influenced by the occurrence of ejection. In addition, the influence of at least two other major variables affecting both the frequency of ejection and the risk of fatality have been definitely established in previous research (*6*, *7*) and have to be taken into account. These factors are accident severity and seated position, both of which are believed to have sufficient bearing on the subject of this investigation to warrant particular attention.

Figure 1 illustrates the frequency of fatality in progressive categories of accident severity. Statistical analysis of the data, revealed a significant increase ($P<.001$) in risk of fatality as accident severity increased. Figure 2 illustrates the frequency of fatality among car occupants according to seated position occupied and shows that the risk of fatality was significantly different ($P<.001$) for occupants of different positions. In these two figures, in order to eliminate over-emphasizing driver injury, data on drivers alone and drivers with passengers are presented separately.

The effect of these same factors on the frequency of ejection is illustrated in figures 3 and 4. Figure 3 illustrates that as accident severity progressively increased, the frequency of ejection significantly increased ($P<.001$). Figure 4 illustrates the varying and significantly different ($P<.001$) frequencies of ejection depending on seated position. In particular, the rear seat area produced much lower risk of ejection than the front seat area. This was due largely to the fact that about half of the cars observed were two-door models; rear seat occupants were seldom ejected through the front doors.

Observed and Expected Risks

It has been clearly demonstrated that those ejected are much different from those not ejected with respect to risk of fatality and that, further, fatality risks will fluctuate considerably according to seated position and accident severity. The available data on these three factors affecting fatality risks were used to determine the answer to the question: What would have been the expectations in terms of fatality for the ejected had they remained inside the cars?

Strictly speaking, of course, it is impossible to determine what would have happened to any specific ejected person in a single, hypothetical situation if he had remained inside the car. However, given certain reasonable assumptions,

Figure 1. Frequency of fatality according to accident severity.

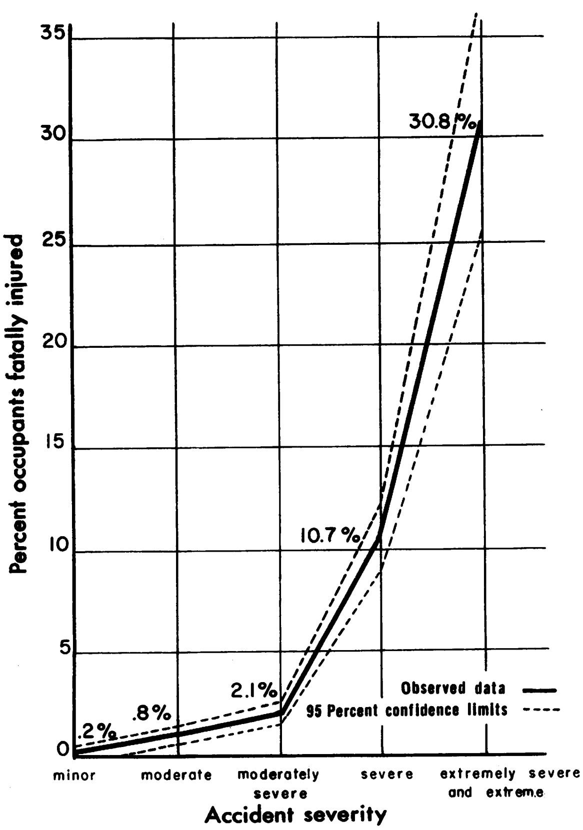
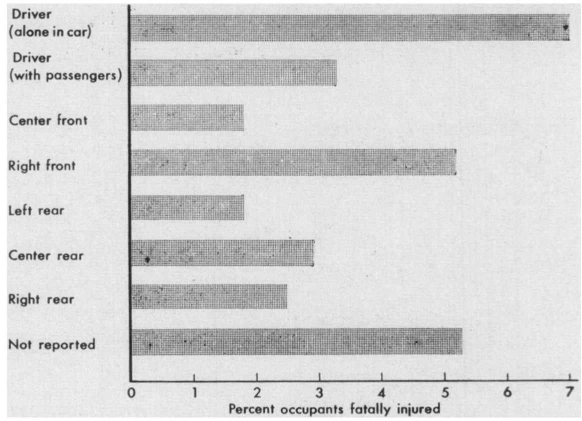


Figure 2. Frequency of fatality among all occupants of different seats.



it is possible to obtain an estimated (or predicted) number of fatalities representing the fatality risk of a category or group rather than of any individual in that category or group. Predictions under such conditions are described as expectations under a given hypothesis or, more briefly, expectations.

The volume of data on nonejected persons, 81.6 percent of the total number in this study, is sufficiently large so that the risks of fatal injury associated with given seated positions under given conditions of accident severity may be assumed to be representative for any single occupant who remains inside the car. A reasonable assumption is that the fatality risks to which a given ejected person would be exposed were he not ejected would be comparable to the fatality risk encountered by a group of nonejected occupants subjected to the same conditions of accident severity in a seated position corresponding to that from which the ejected person had been thrown. The fatality risks for nonejected persons according to accident severity and seated position can be taken directly from basic data. These observed fatality risks thus obtained provide a reasonable basis for calculating the expected number of fatalities that would have been encountered among ejected persons if they had stayed in their seats.

Calculations for Expectancies

Simple algebraic calculations, based on the rationale described above, yielded the expected number of fatalities in each category of accident severity and seated position. For example, it is shown from the data in table 2 that among 578 nonejected right front seat occupants involved in moderately severe accidents, there were 6 fatalities, while among 115 ejected right front seat passengers in accidents of the same severity, there were 14 fatalities. To calculate the expected number of fatalities if ejection had not taken place, the data were arranged as a simple ratio: the expected number of fatalities among the ejected is to the total ejected as the observed number of fatalities among the nonejected is to the total nonejected. Expressed numerically, the ratio reads, $x : 115 :: 6 : 578$.

The expected number of fatalities among ejected persons was 1.19 (or about 1 person). But among the 115 ejected persons observed, there were actually 14 killed. Thus, in the given category of seated position and accident

Figure 3. Frequency of ejection according to accident severity.

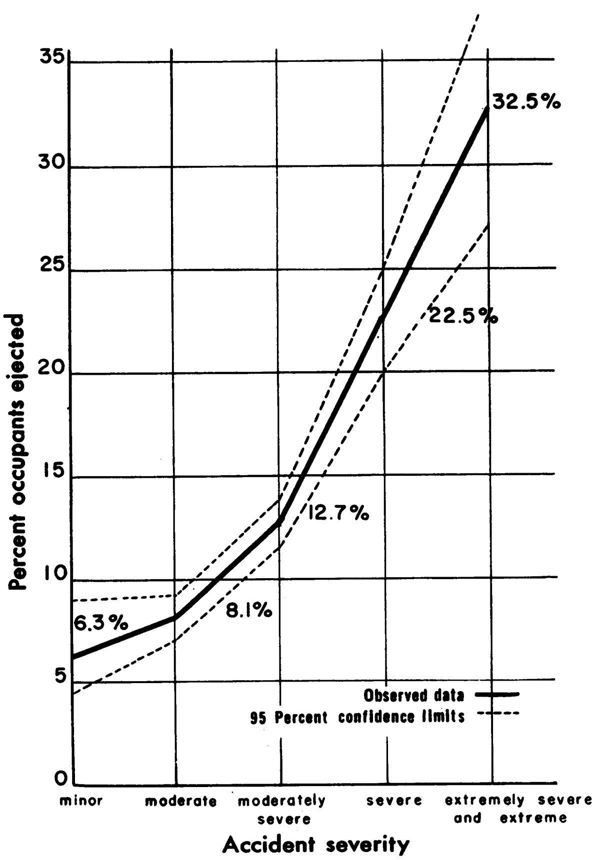
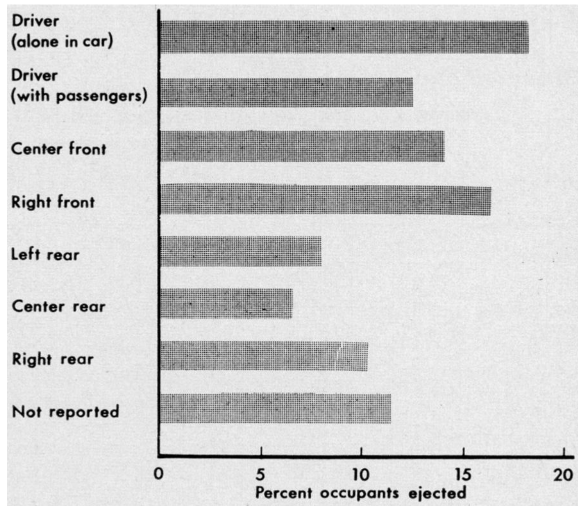


Figure 4. Frequency of ejection from different seats.



severity, there were 13 more people killed than would have been expected if there had been no difference between risks of fatality for ejected and nonejected persons.

By totaling the observed and the expected fatalities in table 2 for each seated position and within ranges of severity, and then subtracting one from the other, the basis was provided for an estimate of the number of lives that could have been saved in the 3,261 accidents surveyed if ejection had not occurred. There were 121 observed fatalities and 53 expected fatalities among those ejected, a difference of 68, therefore, between the two.

The total number of fatalities observed among all occupants, whether ejected or not, was 268. Since 147 of these were among the nonejected group, they would not be affected by preventing ejection, and the expected number of fatalities here would be the same as the number observed. Therefore, preventing ejection could have reduced the number of fatalities by 68, leaving only 200 fatalities. (The 200 expected fatalities could also have been determined in this way: 147 observed among nonejected, plus 53 expected among ejected under the hypothesis.)

This reduction, expressed as the proportion 200/268 (74.6 percent), can be applied to the national fatality figures for passenger car occupants to obtain the estimated number of fatalities that would still occur throughout the Na-

Table 2. Observed and expected fatality frequencies among those ejected, with regard to accident severity and seats occupied

Accident severity, by seat occupied	Nonejected: Total persons observed	Nonejected: Fatally injured persons observed	Ejected: Total persons observed	Ejected: Fatally injured persons observed	Ejected: Fatally injured persons expected
Minor	**436**	**0**	**30**	**1**	**0. 0**
Driver alone	62	0	10	1	. 0
Driver with passenger	122	0	5	0	. 0
Center front	34	0	1	0	. 0
Right front	101	0	9	0	. 0
Left rear	33	0	2	0	. 0
Center rear	20	0	1	0	. 0
Right rear	39	0	2	0	. 0
Seat unreported	25	0	0	0	. 0
Moderate	**2, 025**	**7**	**183**	**8**	**. 63**
Driver alone	265	2	32	3	. 24
Driver with passenger	609	1	42	2	. 0
Center front	177	0	21	1	. 0
Right front	491	2	65	2	. 27
Left rear	131	0	4	0	. 0
Center rear	68	1	3	0	. 04
Right rear	150	0	9	0	. 0
Seat unreported	134	1	7	0	. 05
Moderately severe	**2, 276**	**21**	**351**	**31**	**3. 24**
Driver alone	329	6	70	6	1. 27
Driver with passenger	680	4	100	8	. 59
Center front	187	1	29	0	. 15
Right front	578	6	115	14	1. 19
Left rear	167	0	8	0	. 0
Center rear	79	1	3	0	. 04
Right rear	166	1	11	3	. 07
Seat unreported	90	2	15	0	. 33
Severe	**868**	**75**	**283**	**44**	**24. 45**
Driver alone	126	16	62	12	7. 87
Driver with passenger	241	18	76	9	5. 68
Center front	76	3	22	2	. 87
Right front	215	25	80	16	9. 30
Left rear	62	1	8	0	. 13
Center rear	40	2	4	0	. 0
Right rear	66	5	16	1	1. 21
Seat unreported	42	5	15	4	1. 79
Extremely severe and extreme	**166**	**44**	**96**	**37**	**25. 45**
Driver alone	29	14	23	9	11. 10
Driver with passenger	44	9	24	9	4. 91
Center front	12	2	6	2	1. 00
Right front	37	14	18	6	2. 27
Left rear	7	1	10	6	1. 43
Center rear	9	1	4	2	. 44
Right rear	12	1	7	1	. 58
Seat unreported	16	2	4	2	. 50
Total [1]	5, 771	147	943	121	**24. 02**

[1] Data on 623 of the 7,337 occupants in the sample have been omitted because of incomplete details. Ejection data were not fully reported for 350 persons, and accident severity information was not available for 273.

tion even if ejection were controlled (*3*). Roughly 75 percent would still occur, which means a reduction of 25 percent.

National Fatalities

The National Office of Vital Statistics reported 39,628 deaths resulting from motor vehicle accidents of all descriptions in 1956. The annual figure has been fairly constant over the past 5 years (*5*). Since these tabulations included all persons fatally injured, under whatever circumstances, in accidents associated with motor vehicles of every description, they were not all applicable to the present study, which is concerned exclusively with fatal injury to passenger car occupants. Therefore, certain eliminations were needed in order to obtain the basic applicable figure accounted for by passenger car occupants among the national fatalities.

Among the fatalities eliminated were those incurred when motor vehicles collided with pedestrians or cyclists, since fatal injuries in these accidents were more likely to have been sustained by the latter than by the occupants of the motor vehicles. The nature of the National Safety Council's tabulations, subclassified under various categories, permitted the elimination of these fatalities without difficulty (*5*).

A further elimination was required with respect to fatalities among occupants of street cars, buses, trucks, and any other vehicles which could not be classified as passenger cars. Unfortunately, the national accident fatality tabulations did not distinguish between deaths among occupants of passenger cars and occupants of other motor vehicles. However, gross figures supplied by the National Safety Council (*5*), through data collection of the National Office of Vital Statistics (*8*), provided for the estimation that about 75 percent of the motor vehicles involved in fatal accidents were passenger cars. Most of the remaining 25 percent were trucks, which normally carry fewer passengers than automobiles. Therefore, it is perhaps overgenerous to presume that 25 percent of the fatalities in these accidents were sustained in vehicles other than passenger cars.

The results of all the above eliminations may be observed in table 3.

These eliminations result in a conservative estimate of 23,678 deaths annually among occupants of passenger cars involved in accidents. Roughly 87 percent of these deaths (20,528) occurred in rural accidents; the balance of 13 percent are accounted for by accidents in urban areas. In the following section it is estimated how many of these 23,678 lives might have been saved by preventing ejection. Since the estimate of passenger car occupant fatalities is very cautious, the predicted number of avoidable fatalities may represent an underestimation. In any case, it can safely be regarded as a minimum figure.

Application of Reduction Proportion

We have estimated that prevention of ejection could eliminate 25 percent of the fatalities observed in the study sample. Before applying this percentage to the adjusted estimate of 23,678 annual deaths among passenger car occupants throughout the Nation, certain differences between the sample data and the national tabulations had to be taken into account. For example, among those national fatalities pertinent to the problem (table 3), roughly 20,000 occurred in rural areas and about 3,000 in urban areas, with the ratio of rural to urban fatalities amounting to somewhat more than 6 to 1. In the sample studied the ratio of rural to urban fatalities was about 25 to 1.

Therefore, applied to national figures, the

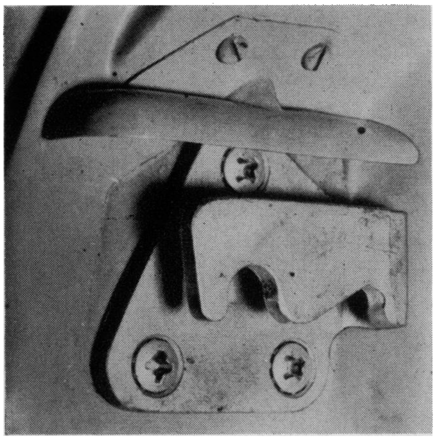
Table 3. Motor vehicle fatalities, 1956 [1]

Classification	Total	Rural	Urban
Total	[2] 40, 000	30, 400	9, 600
Pedestrians, cyclists	8, 430	3, 030	5, 400
Balance	31, 570	27, 370	4, 200
Trucks, buses, others (25 percent of balance)	7, 892	6, 842	1, 050
Balance (passenger cars)	23, 678	20, 528	3, 150

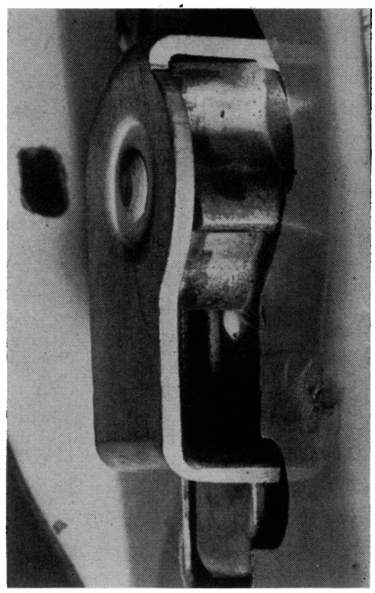
[1] Derived from 1956 fatality figures published in Accident Facts (*5*), and based on mortality data collected by the National Office of Vital Statistics.

[2] A more accurate figure (39,628) has been recently released by the National Office of Vital Statistics, but corresponding adjustments for the detailed groups in the table are not yet available.

Typical safety doorlock.



STRIKER



LATCH ASSEMBLY

STRIKER AND
LATCH ENGAGED

calculation for the percentage of reduction would have to take into account the sampling bias.

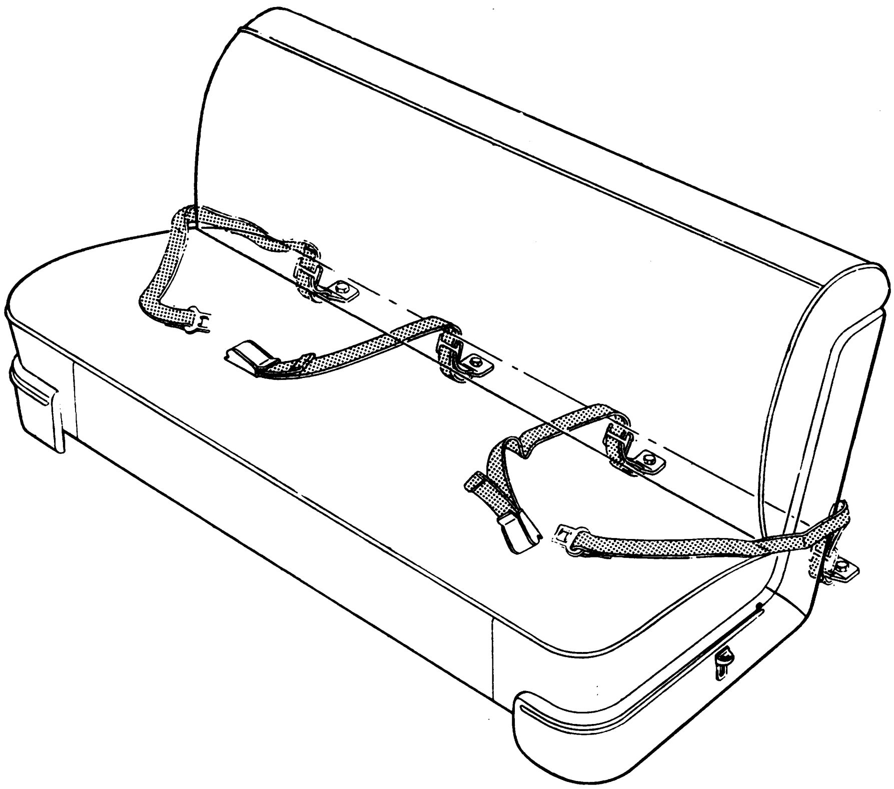
Since the sample was predominantly rural (more than 90 percent of the accidents studied occurred in nonurban areas), the estimated reduction of 25 percent could be directly applied to the 20,528 lives lost annually in rural accidents, a saving of about 5,132 lives each year. However, the full reduction of 25 percent could not be reasonably expected in urban accidents where accident conditions are frequently less severe than on rural roads. It was estimated that perhaps a 10 percent reduction could be presumed, and that about 315 of the 3,150 urban fatalities might be eliminated by prevention of ejection. Thus, a minimum of approximately 5,500 annual fatalities might be avoided in future years if the hazards of ejection were removed.

Discussion

An annual toll of approximately 40,000 deaths and more than 1,000,000 injuries (*5*, *8*) in motor vehicle accidents is truly epidemic in proportion, and is not likely to be brought under control except by preventive methods affecting a majority of the national population. Obviously, the ideal solution would be the elimination of accidents themselves, but it clearly must be assumed that a certain number of accidents will always take place. Furthermore, large-scale measures to prevent accidents may take years to develop.

If it is admitted that some accidents will always occur despite all efforts, then proper attention to the crash injury problem should include development and provision of controls that will operate to prevent injury when an accident occurs. Controls of this sort may be compared to the use in preventive medicine of serums and vaccines which protect the recipient from the consequences of exposure to infectious diseases.

It is the objective of automotive crash injury investigations to isolate and identify the specific causes of injury observed in injury-producing accidents, and to provide indications of the fre-



Typical seat belt installation.

quency, nature, and severity of injuries associated with given causes. Reliable data of this kind can guide designers and engineers toward the elimination or delethalization of specific structures found to be potentially dangerous under crash conditions.

The relationship of automobile design to injury is nowhere more apparent than in the comparison of the frequency of fatality among ejected and nonejected occupants. If doors had not sprung open during impact, occupants could not have been ejected. Even if doors had failed to remain closed, by our definition of complete ejection, no occupant wearing a fully effective seat belt could have been thrown from the car. As statistical computation has indicated, 25 percent of all fatalities among passenger car occupants can be eliminated if ejection is completely prevented. Failure to control ejection implies the loss of more than 5,000 lives each year, and these deaths can no longer be accepted as unavoidable since the means of at least partial control exists.

If occupants can be retained inside the car in future accidents, then the injury potential associated with structures within the passenger compartment can be reduced systematically with the cooperation of the automotive engineer. The use of properly designed and installed seat belts, for example, not only protects the wearer from the risks associated with ejection but also reduces the force with which he is likely to strike objects within the passenger compartment. It has been observed under controlled laboratory conditions that the restraining action of a lap-type seat belt reduces the force of head blows by as much as one-third (*9*). If objects and surfaces within the reduced striking range of a seat-belt wearer are designed to absorb energy and to distribute it over a considerable area of the contacting body, a further reduction in injury-producing force is readily obtained. Preliminary studies, utilizing a paired-comparison technique, have indicated that the use of seat belts by nonejected persons is associated with a maximum demonstrable decrease of about 60 percent in risk of all grades of injury (*2*, *4*).

Additional design modifications can be suggested, and new developments tested as they become available. At present, data from more than 10,000 automobile accidents are available for use as a control group in evaluating future safety designs.

Although the present report has been concerned with ejection only as it influences the incidence of fatal injuries, the importance of ejection in nonfatal injuries, particularly those that are seriously disfiguring or disabling, should not be overlooked. Unfortunately, data are not available to predict the national reduction in nonfatal injuries that might be expected if ejection should be prevented. However, there is evidence that the percentage of passenger car occupants sustaining serious and critical injuries, whether ejected or not, is roughly the same as the percentage who are fatally injured. Previously published research findings have indicated that the number of fatal injuries sustained by passenger car occupants is similar to the number of serious-to-critical (dangerous) injuries (*3*). Thus, among those persons injured nonfatally in motor vehicle accidents each year, there might be some 23,670 passenger car occupants whose injuries are in the serious-to-critical range, and whose risk of sustaining injuries of this severity is at least doubled when ejection takes place. (The calculated ratio is 2.5 to 1.) Effective prevention of ejection could scarcely fail to produce a substantial reduction in the annual number of serious-to-critical injuries.

Although it is not a function of the present research in automotive crash injuries to develop the actual devices for control and elimination of the ejection hazard, data and findings suggest the provision of strengthened door locks in currently manufactured cars, automobile seat belts, and some simple and effective device for keeping doors closed on the more than 50 million pre-1956 cars still operating today.

One serious limitation of devices such as the seat belt relates to the educational and psychological difficulties in bringing about their general acceptance and use. Inevitably, a considerable number of automobile users will show more than initial resistance. But it is believed that extensive efforts aimed at encouraging widespread use of seat belts, together with constant modification of automobile components identified as responsible for injury, will result in a significant reduction of highway casualties.

Application of the means for controlling ejection and its injurious effects is within the realm of immediate possibility. It is hoped that the goal of an annual saving of several thousand lives will provide the needed incentive.

Summary

In a sample of injury-producing accidents analyzed in the Cornell University Medical College study (3,261 passenger cars, each of which contained at least 1 injured person), 13.6 percent of all occupants were completely ejected from an automobile.

Ejected occupants of passenger automobiles had a much higher risk of fatality than those not ejected. This increase was demonstrated to be statistically significant and not due to chance.

The frequency of ejection from doors opened under crash impact conditions varied according to accident severity and seat occupied. Fatality risk was also influenced by these two factors.

Observed and expected fatalities based on a simultaneous consideration of ejection risk, accident severity, and seat occupied demonstrated that prevention of ejection from passenger cars could have reduced fatalities among passenger car occupants in the study by 25 percent.

It is conservatively estimated that about 23,700 of the approximately 40,000 lives lost annually occur among passenger automobile occupants involved in traffic accidents. Of these fatalities, about 20,000 occur in rural areas.

Elimination of ejection in passenger automobile accidents on a nationwide scale could save a conservatively estimated 5,500 lives yearly if the level of annual fatalities persists at about 40,000.

Ejection from automobiles can be prevented by the use of properly designed and installed seat belts, further refinements of the safety door lock which was standard equipment in 1956 and 1957 cars, and auxiliary devices designed to keep doors closed in older cars.

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Advisory Committee on Radiation

A National Advisory Committee on Radiation was established by the Surgeon General of the Public Health Service February 12, 1958, to advise on programs of the Service in public health aspects of radiation.

Present Service activities in this field include research, epidemiological studies, radiation monitoring of water, air, and milk, and technical assistance to the States on safety measures.

Dr. Russell H. Morgan, professor of radiology, Johns Hopkins University Medical School and radiologist in chief, Johns Hopkins Hospital, who has been serving as special consultant on these matters, is committee chairman. Dr. Donald R. Chadwick of the Office of the Surgeon General is executive secretary.

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