Crash Protection for Older Persons

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Crash protection as a fundamental design parameter for motor vehicles has achieved recognition only within the last 20 years. The body of scientific knowledge on which effective crash-protective design is based is still relatively small, and is as yet inadequate to allow optimum protection to be specified for the various populations at risk. The input characteristics of crash type, direction, severity, and frequency are reasonably well defined, but the characteristics of the populations so exposed are less well understood. Age, sex, height, and weight are well documented, but tolerance to blunt impacts (which is involved in almost all traffic injuries) and how this tolerance varies throughout the population at risk have been inadequately researched. The outcome parameters of injury severity and frequency, disability, financial cost, and loss in quality of life are similarly poorly defined and delineated.

Conflicts are immediately apparent. If designs are optimized primarily to prevent death among young men, for example, such designs can be far from optimal in minimizing the incidence of the vastly greater number of injuries of lesser severity for the more vulnerable sections of the population at risk. Optimizing vehicle structures for good performance in quasi-legal 35-mph New-Car Assessment Program (NCAP) tests results in particularly hostile vehicles in side-impact collisions with another car at an intersection. Exterior design to minimize trauma to pedestrians leads to lower bumper heights and softer front end structures. These are in conflict with current non-safety-oriented economic standards that govern bumper design.

Nowhere are these conflicts clearer than when a particular segment of the population, such as older persons, is considered. This review will not be able to produce definitive and detailed recommendations justifiable when measured against the yardsticks of classical epidemiology. That is because there are substantial gaps in the knowledge of frequency, circumstances, nature, and consequences of traffic injuries. However, there is much recent empirical work that offers great promise, and this review will focus specifically on these evolving technologies, which offer specific benefits for older persons. Much of current crash-protective design will help the whole population in a general way, but selection of priorities for older persons is more difficult. Cost-benefit criteria are normally employed in establishing such priorities, but for older persons particularly, there are many difficulties and uncertainties in using strict financial criteria. Some of these issues will be addressed in the following sections.

The purpose of this review, therefore, is to summarize some of the exposure and epidemiological characteristics of older persons in terms of their involvement in crashes as car occupants or pedestrians. Very few older persons are casualties in other categories of road user, such as cyclists and motorcyclists, in the United States. In passing, however, it is worth noting that older persons are frequently injured as cyclists and moped riders in several other countries, some of which are fully industrialized, such as Holland, France, and Japan. This might also become true in some sections of the United States where the climate is appropriate.

After a discussion of the biomechanical characteristics of older persons, the general principles of crash-protective design and some of the new technologies particularly appropriate for older persons are reviewed.

Pedestrian crash protection is covered, and then some suggestions are made for improved crash performance of vehicles to recognize the specific requirements of older persons.

Finally, there is a short discussion on general policy issues relating to crash protection and future research needs, with some specific conclusions and recommendations for the near-term and long-term perspectives.

EXPOSURE ISSUES

In the context of biomechanics and crash performance there is no simple definition of older persons. It is well established that the aging process reduces tolerance to crash forces. This applies not only to bone strength and fracture tolerance but also to the consequences of a given insult for other types of injury. For example, residual brain dysfunction following a given initial injury is greater in older persons than in younger age groups. Likewise the risk of death is significantly dependent on age following a given exposure. Yet such averaging ignores very substantial variations in physiological characteristics, partly because these characteristics are themselves not well defined. Thus, chronological age is the only available parameter to use in reviewing exposure issues for older persons, but functional age as opposed to chronological age varies substantially in the context of biomechanics.

As is common in most industrial countries, older persons are the fastest-growing segment of the U.S. population. Just over 12 percent of the U.S. population are over 65 years of age. For the seven largest countries in the Organization for Economic Cooperation and Development, 12.5 percent are over 65 and by 2025 that number will rise to 20 percent. In West Germany and Japan by 2025, 1 person in 10 will be 75 or over. Currently in the U.S. 11 percent of current license holders are 65 and over.

The general exposure of older persons has been well documented elsewhere *(1)*, but some conclusions relevant to crash performance are worth summarizing here. For further discussion of exposure and documentation, see Chapter 3, Safety of Older Persons in Traffic, in Volume 1 of this study.

Once involved in a road crash, those over 65 have a higher risk of being seriously injured (AIS > 3) or killed than younger age groups (Table 1). [AIS refers to the Abbreviated Injury Scale, an internationally agreed-on scale that

TABLE 1 AGE DISTRIBUTION OF THOSE INVOLVED AND INJURED IN ACCIDENTS, 1979–1980 *(2)*

		Age Distribution (%)			
	No. of Involved	Involved	Injured	Seriously Injured	Fatally Injured
Under 5	543,000	3.1	2.7	1.5	2.2
5–9	353,000	2.0	2.7	3.0	2.5
10–14	511,000	2.9	3.7	6.7	2.8
15–24	6,467,000	36.4	40.3	35.1	36.3
25–34	3,520,000	10.3	10.0	7.9	9.9
35–44	1,838,000	10.3	10.0	7.9	9.9
45–54	1,476,000	8.3	7.6	8.2	7.9
55–64	991,000	5.6	5.6	6.3	7.1
65+	893,000	5.0	5.6	8.3	10.5
Unknown	1,185,000	6.7	0.4	0.2	0.6
Total	17,777,000				

classifies the severity of injuries to a person overall and by body region on a scale from 1 (minor) to 6 (death). It relates predominantly to the threat to life from a given type of injury.] This is shown more specifically in Figure 1, where the mortality for specific Injury Severity Scores (ISS), which is the sum of the square of the AIS values for the three most seriously injured body regions, is shown to be strongly age dependent.

Involvement rates (crashes per 10^8 vehicle-mi) for car drivers rise substantially over 65 years, but absolute numbers remain low because of reduced

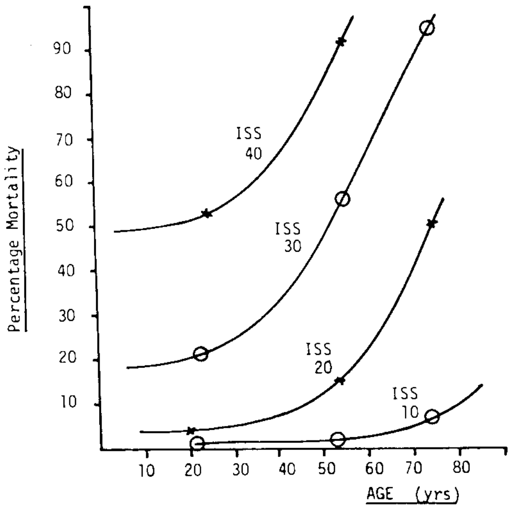


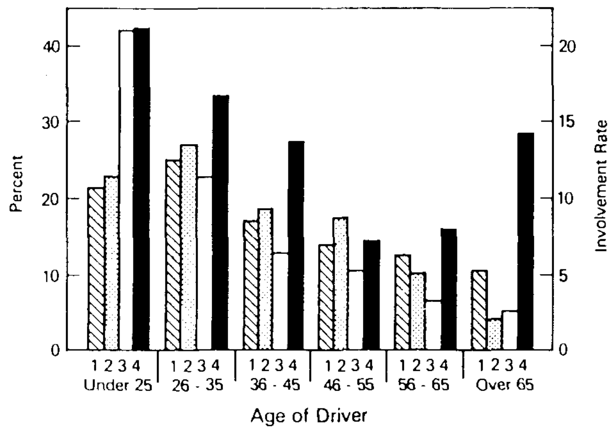
FIGURE 1 Mortality at different ages for ISS 10, 20, 30, and 40 *(3)*.

mileage driven (Figure 2). Fatality rates (fatalities per million population in a specific age group) rise significantly, but only for those 75 and over (Figure 3).

As pedestrians, older persons are overrepresented in both casualties and deaths. Overall, pedestrians make up 16 percent of all traffic deaths in the United States. For traffic deaths involving those over 65, pedestrians make up 27 percent. That proportion is likely to rise substantially as improved technologies and legislation focus on reducing car occupant casualties. For example, in Great Britain, with 95 percent use of front-seat car occupant restraints in 1986, pedestrian and car occupant deaths are almost equal for all ages—35 and 40 percent, respectively. The equivalent numbers for the United States are 16 and 65 percent.

With retirement, substantial changes in life-style can occur, which result in different exposure to risk of involvement in various types of traffic collisions. These general exposure issues are beyond the scope of this review, but they suggest that the exposure and needs of older persons in terms of crash involvement may be significantly different from those of the younger population.

Without an extensive amount of epidemiological investigation, it is not possible to delineate these differences, and there are doubtless substantial geographical and economic factors that confuse the picture. However, there may well be a significant enough older population with different vehicle use requirements and different exposure to crash involvement to justify a vehicle



1 — Percent of Total Licensed Drivers

2 — Percent of Vehicle Miles Traveled

3 — Percent of Accident-involved Drivers

4 — Involvement Rates (Accidents per 100 million vehicle miles)

FIGURE 2 Age distribution of accident-involved drivers, 1979–1980 annual average *(2)*.

with specific design characteristics suited to their needs. These design characteristics would include crash performance optimized for the exposure needs of older persons.

For example, one can envisage a relatively small, maneuverable, two-seated vehicle with an interior designed specifically in ergonomic terms and with a very high level of crash performance. Such a vehicle would be specifically propedestrian in design and would meet the highest standards of emission and noise control. In concept this approach might be attractive to relatively affluent older people who live in cities or suburbs with relatively low mileage requirements.

General market trends in vehicle design suggest an increasing fragmentation of the vehicle fleet, with growing numbers of vehicles having special characteristics. The high growth rates of speciality cars—pick-ups, urban vans, car-van hybrids, high-performance cars and other automobiles, offering attractions to particular segments of the marketplace—suggest that there might be a slot for a vehicle with particular attraction for older persons. Clearly, better market intelligence is needed on this point.

Another major exposure difference for older persons in comparison with the younger population is as pedestrians. With retirement comes more walking during the daytime; with a reduction in driving there is an increase in the use of public transport for many older persons and associated with that change in

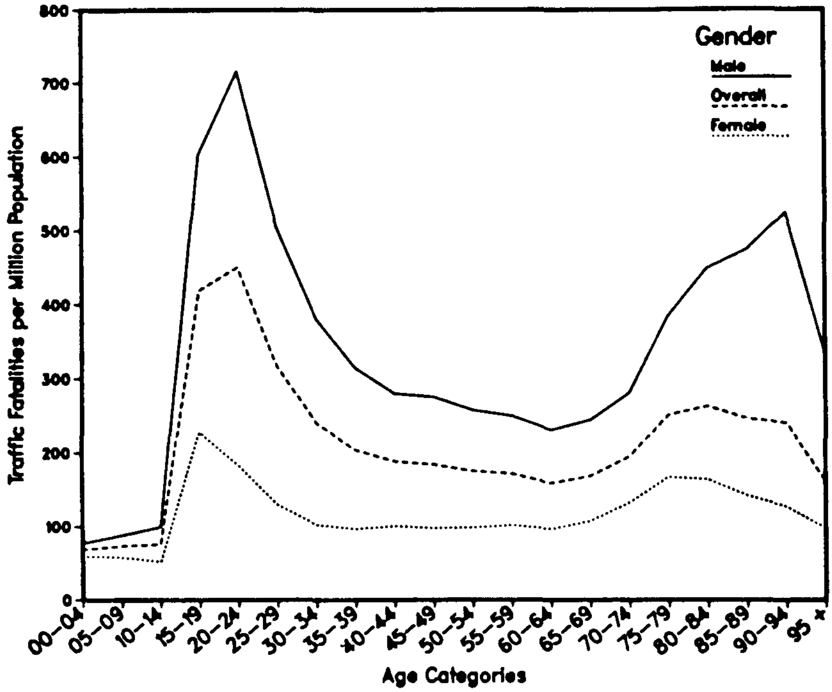


FIGURE 3 Traffic fatalities per million population in 1980 *(4)*.

travel mode comes increased exposure as a pedestrian. Doubtless such changes are partly behind the great increase in pedestrian deaths after age 65 (Figure 4).

EPIDEMIOLOGICAL ASPECTS

Car Occupants

A number of studies outline general patterns of injuries and their severities, but no work appears to have been specifically related to age differences and changing injury patterns. The National Crash Severity Study (NCSS) tabulations show that for all ages the relative frequency of body regions involved varies greatly according to injury severity (Table 2).

A characteristic of serious traffic casualties is the multiplicity of trauma. For the average unrestrained occupant with an overall injury severity of AIS 3, there are 1.3 injuries at the AIS-3 level. For the average fatality there are 2.3 injuries at AIS 3 or more.

It should be recalled that the AIS is a scale of threat to life and does not assess long-term consequences. This is particularly relevant to older persons,

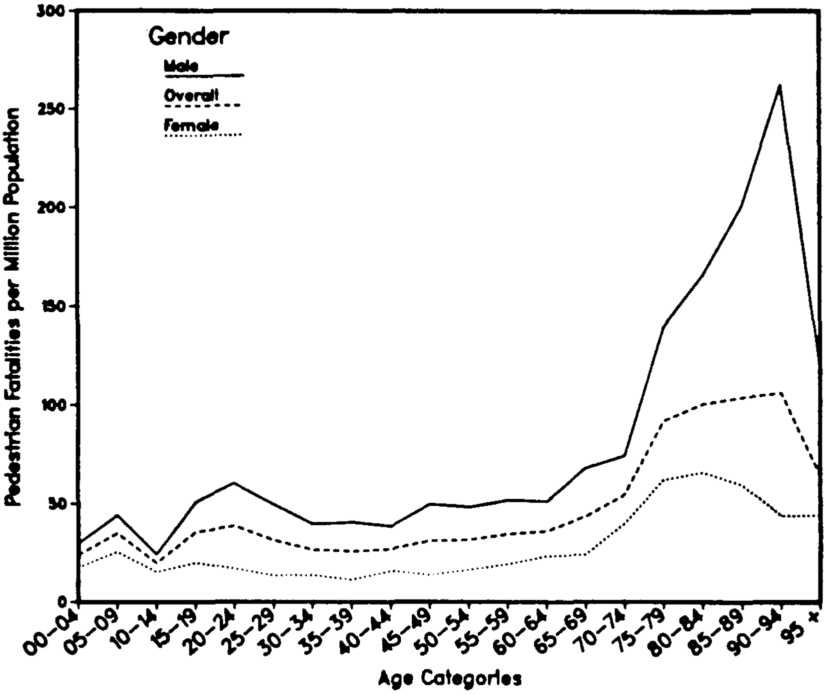


FIGURE 4 Nonoccupant (pedestrian and cycle) fatalities per million population in 1980 *(4)*.

TABLE 2 RELATIVE FREQUENCY OF BODY REGIONS INVOLVED IN INJURIES, 1980 *(5)*

	Percentage of Injuries by Severity Level		
Body Region	AIS 1 (N = 19,138)	AIS 3 (N = 2,531)	AIS 6 (N = 212)
Head	43.0	10.2	29.7
Leg	19.1	26.1	–
Arm	15.2	12.8	–
Thorax	6.8	36.6	23.1
Neck	8.9	4.2	43.4
Back	4.6	1.9	0.9
Abdomen	1.9	8.3	1.4
Whole body	0.5	–	1.4

who do not recover normal function easily. Because of the relative frailness of older persons, distributions of less severe injuries are particularly interesting. AIS-2 injuries probably lead to more significant impairment of function in older persons, especially those to the head, limbs, and back. NCSS data on the relative frequency of such injuries are given in Table 3.

TABLE 3 AIS-2 INJURIES BY BODY REGION, 1980 *(5)*

Body Region	No.	Percent
Head	2,053	50.1
Leg	879	21.4
Arm	707	17.2
Thorax	259	6.3
Neck	37	0.9
Back	148	3.6
Abdomen	16	0.4
Whole body	1	0.0
Total	4,100	

The more serious consequences of a given initial injury severity for older persons are shown in Table 4 *(6)*. For example, AIS-3 injuries for those under 50 require 9.7 days of hospitalization. For those over 69 the same injury requires 13.7 days. Apart from subsequent loss of function, on strictly cost terms alone, these data show that lesser levels of injury to older persons are more expensive than the same injuries sustained by younger people.

TABLE 4 DAYS IN HOSPITAL AS A FUNCTION OF AIS AND AGE *(6)*

Age	AIS	No.	Days	Avg Days
Under 50	1	15,065	2,861	0.1899
	2	3,268	7,825	2.3944
	3	1,422	13,795	9.7011
	4	369	6,659	18.0461
	5	111	3,999	36.0270
50–69	1	2,033	974	0.4791
	2	489	1,451	2.9673
	3	327	3,708	11.3394
	4	57	1,597	28.0175
	5	13	609	46.8462
Over 69	1	515	357	0.6932
	2	157	1,484	9.4522
	3	110	1,506	13.6909
	4	15	340	22.6667
	5	3	175	58.3333

Crash Severity

Cumulative frequency curves of crash severity exposure assessed by the computed velocity change during the crash phase are available in a number of studies, notably the NCSS *(5)*. Figure 5 shows the general relationships between velocity change and injury severity: 80 percent of AIS-3+ injuries and 50 percent of fatalities occur at changes in velocity of 33 mph or less. The curves in Figure 5 show that the conditions that generate many severe injuries are not ones of enormous speed and energy. Thus, changes in the specifics of

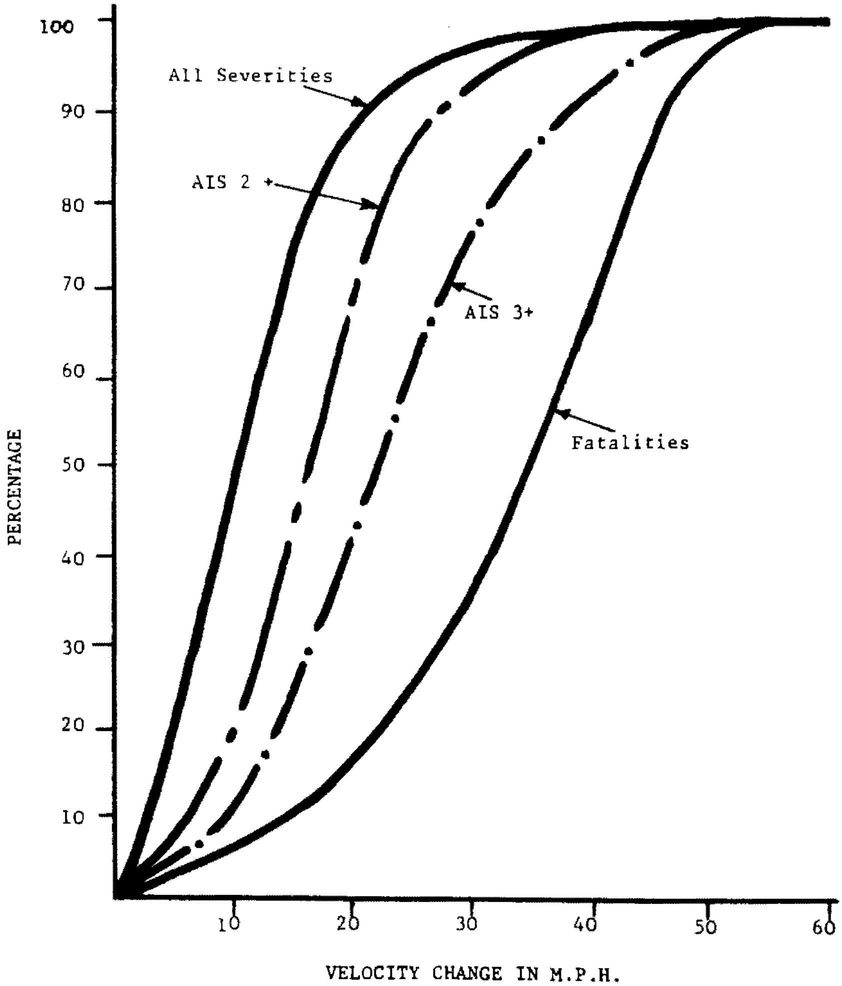


FIGURE 5 Crash severity and injury severity *(5)*.

occupant contact achieved by improved crash-protective design can significantly benefit such population distributions.

For example, if the threshold of contact forces that produce fatal injuries at around 30 mph were increased by, say, 5 mph, because of the steepness of the middle part of the curves in Figure 5, such a small improvement in the threshold for the generation of fatal injury would lead to a significant overall reduction in the number of fatalities.

Age and probability of serious injury (AIS 3+) have been related to crash severity in Figure 6 *(2)*. These data, which are for frontal collisions, show the age effect to be pronounced. The probability of death or serious injury is increased by about 70 percent for those over 60 years of age in comparison with the 20-year-old group *(3)*. Alternatively, the data show that the same probability of serious injury occurs in a crash at a velocity change 7 mph less for the 60-year-old group in comparison with the 20-year-olds.

As a comparison, data from a European study (Figure 7) show the influence of seat-belt use on fatalities in frontal collisions *(7)*. The effect of restraint use is to shift the distribution approximately 6 mph. Such an analysis relates

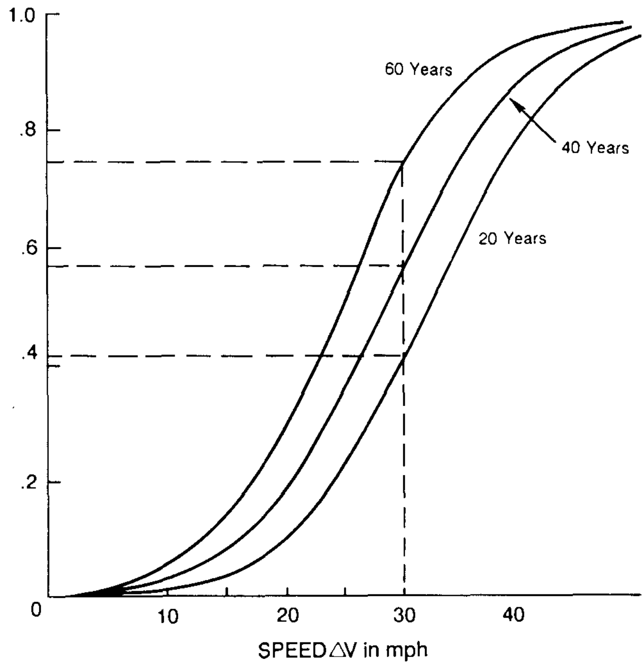


FIGURE 6 Probability of serious injury by age and crash severity *(2)*.

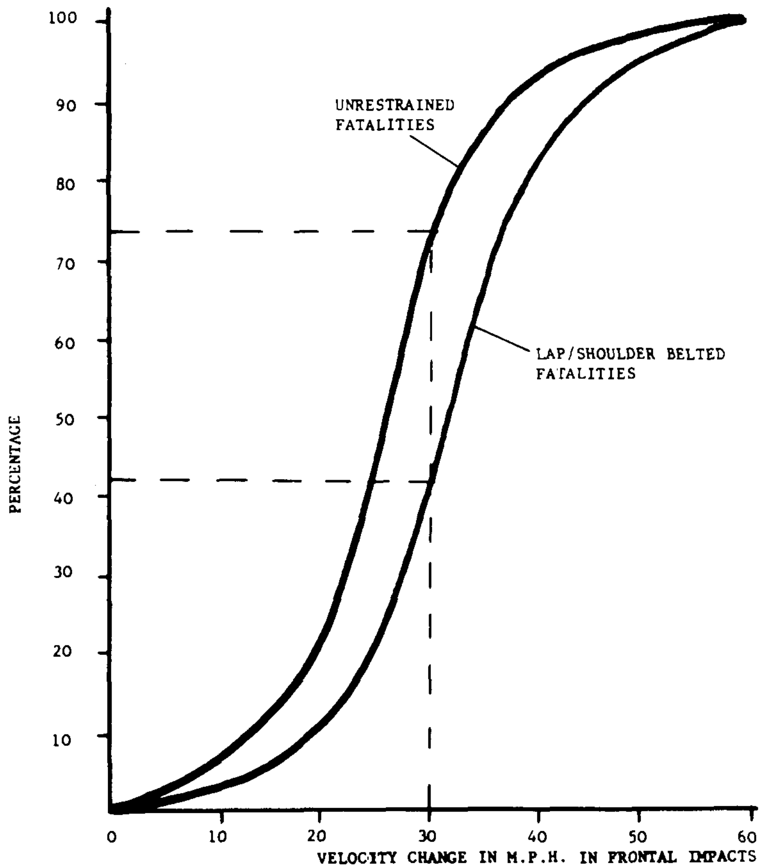


FIGURE 7 Effect of seat-belt use on fatalities *(7)*.

purely to cars in which there is a fatality and does not indicate the benefits of restraints in crashes with lesser levels of injury.

Age and Crash Configuration

Studies in both North America and Europe show a distinct relationship between age and the frequency of various types of collisions. The most detailed study available relates to side impacts; it demonstrates several aspects of crash protection for older persons *(8)*. Data (Table 5) show that young drivers mainly have fatal loss-of-control side impacts with rigid objects off the highway. In contrast, those over 55 have 88 percent of fatalities in vehicle-to-vehicle collisions, and only 12 percent involve off-road objects.

TABLE 5 FATALITIES IN SIDE IMPACTS *(8)*

	Age (years)					
	<35		36–55		>55	
Object Struck	No.	Percent	No.	Percent	No.	Percent
Other vehicle	61	35	36	74	64	88
Rigid object	115	65	13	26	9	12

The same study describes the relationship between the velocity change of the struck car and the age of occupants on the struck side who died. These data (Figure 8) show a substantial scatter, but a discernible inverse relationship is clear in which, for car-to-car collisions, the over-60 age group is the most affected, particularly at lower speeds (Table 6). The authors propose an age-dependent threshold for survival in terms of a tolerable velocity change in current-technology cars. It is the curve marked *A* in Figure 8.

In general, one may conclude that, as car occupants, older persons in comparison with younger age groups are

- More seriously injured for a given crash exposure,
- Hospitalized longer for a given initial injury severity,
- Exposed to fewer high-speed frontal collisions,
- Exposed to more car-to-car side collisions, and
- Among survivors, are exposed to more disabling injuries, which are predominantly to the head and lower limbs.

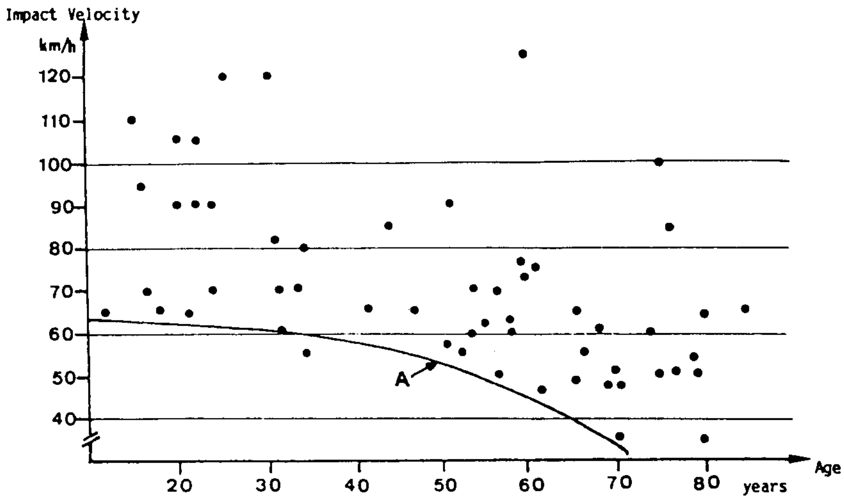


FIGURE 8 Age of fatalities in car-to-car side collisions versus impact velocity (N = 50) (A = age-dependent threshold for survival) *(8)*.

TABLE 6 AGE OF STRUCK-SIDE FATALITIES IN CAR-TO-CAR SIDE IMPACT COLLISIONS *(8)*

Relative Velocity (mph)	Percentage of Fatalities by Age (years)		
	<40	40–60	>60
<33	0	14	86
<39	13	33	54
<45	24	32	44
<51	27	31	42

Pedestrians

Of pedestrian fatalities in the United States, those over 64 years old constitute 21 percent; there were 1,422 such fatalities in 1986. That compares with 4,408 car occupant fatalities who were over 64. The susceptibility of older persons to serious injury and death is clear from a number of sample studies. For example, Figure 9 *(9)*, which is based on U.K. data, shows increasing proportions of more severe injuries with increasing age. This is shown in greater detail in Figure 10; for adults the incidence of head injury declines somewhat with age, whereas the incidence of lower-limb and pelvic injuries increases. Detailed at-the-scene studies of pedestrian injuries have demonstrated the importance of vehicle exterior shape. Figure 11 shows that a bumper that protrudes ahead of the hood line generates significantly more lower-limb

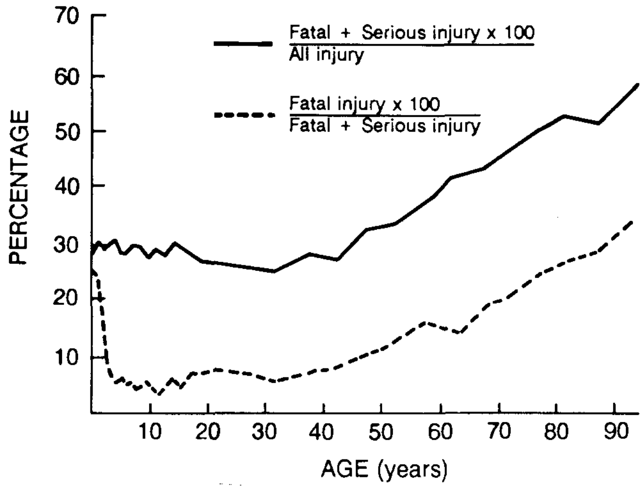


FIGURE 9 Susceptibility of pedestrians to different injury severities by age *(9)*.

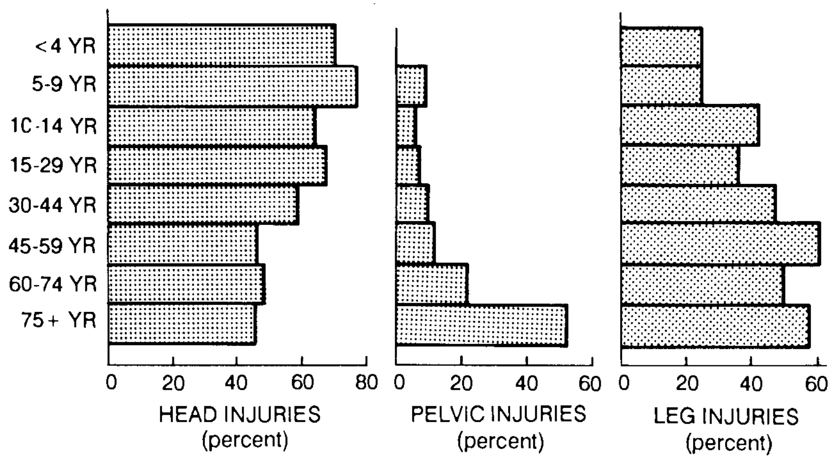


FIGURE 10 Incidence of AIS-2 and -3 head, pelvic, and lower-limb injuries for pedestrians by age (N = 736) *(9)*.

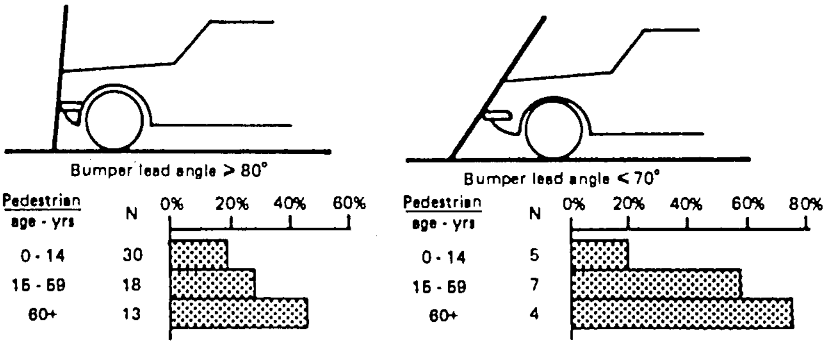


FIGURE 11 Variation in fracture incidence by pedestrian age and bumper lead angle for pedestrian struck at speeds of 21 to 40 km/hr *(9)*.

fractures than does a more upright contour *(9)*. That effect is particularly marked for those over 60.

These findings show that several lower-energy contacts distributed among different points on the lower limb are preferable to a single contact concentrated specifically at adult knee height. A bumper with this type of pro-pedestrian external design will be especially beneficial for older persons.

About 90 percent of pedestrian casualties occur in urban areas, where vehicle speeds are relatively low. The distribution of impact speeds in the United States for all injury severities is shown in Figure 12. About 65 percent

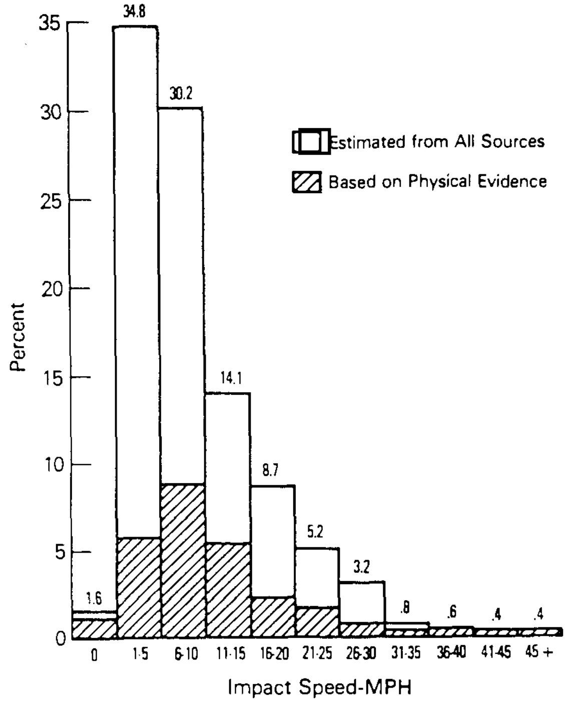


FIGURE 12 Distribution of impact speeds in urban pedestrian collisions *(2)*.

are estimated as occurring at speeds below 10 mph *(2)*. More detailed distributions are shown in Figure 13, where the mean speed for serious injuries [AIS 2+ in this study *(9)*] is 21 mph.

A substantial amount of detailed crash investigation and experimental studies have elaborated the findings on the nature of the shape and compliance of the vehicle exterior. These can be summarized as follows:

- The vehicle, not the ground, causes most of the serious injuries to the pedestrian;
- A long bumper lead is hostile for the legs and may increase the head impact velocity;
- The base of the windshield for small cars is a hostile zone, frequently struck by the heads of adults;
- The front edge of the hood of many cars leads to serious pelvic and femur injuries, particularly in older persons—a smooth curving contour rising from mid-calf is the preferred profile to minimize trauma to the lower limbs; and

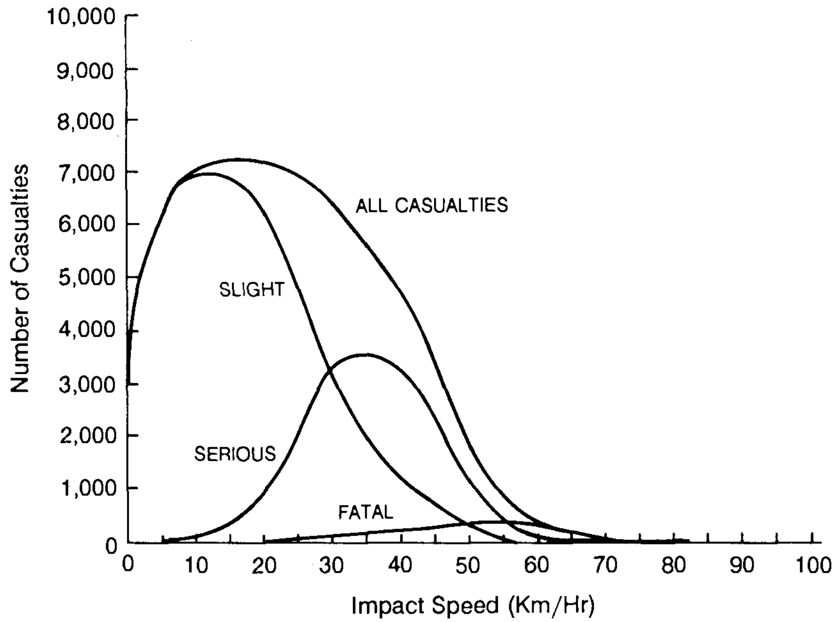


FIGURE 13 Impact-speed distributions for pedestrians struck by the front of an automobile *(10)*.

- The hood can be designed to provide a yielding contact for the head and protection against direct contact with the stiff lower edge of the windshield frame.

It is difficult to predict the benefits of these design changes because current epidemiological data for pedestrians are inadequate. However, in one study it was suggested that if all AIS-2+ leg injuries from the bumper could be eliminated at speeds below 15 mph, there would be a reduction of about 25 percent in overall AIS-2+ pedestrian casualties *(10)*.

BIOMECHANICAL CHARACTERISTICS OF THE ELDERLY

A number of age-related phenomena apply to the ability of the human frame to tolerate blunt trauma. The most well-researched is bone strength. Mineral content of bone, particularly calcium, diminishes with age and with it the breaking strength. Osteoporotic conditions occur in some 20 percent of women over 55, and this pathological condition can also be a consequence of inactivity as a result of some incapacity *(11)*.

The importance of this lowering of the threshold forces to produce fracture has been examined both experimentally and in crash injury field studies. Figure 14 shows the increasing number of rib fractures occurring from the shoulder section of a seat belt for a given sled test deceleration: an average increase of about 3.75, or an increase in injury severity of 0.6 on the AIS scale, per decade over 20 years of age is shown *(12)*.

This implies that an impact load that just begins to produce rib fractures with no displacement when applied to the chest of a 25-year-old man by a standard seat belt may well generate in a 65-year-old multiple, life-threatening fractures with a flail segment, often associated with damage to internal thoracic organs.

This same finding has been shown in crash studies with front-seat occupants using lap and shoulder belts. When standardized by crash severity, the incidence of AIS-2+ chest injuries increases from about 9 percent for 20 to 30 years of age to 35 percent for those over 65 *(13)* (Figure 15).

Besides such quantifiable changes as fracture resistance of bones, the aging process results in other changes to both bone and connnective tissues. Collagen fibers make up much of the matrix of bone as well as being the principal mechanical component in ligaments, cartilage, and muscles. Age produces a loss of extensibility in collagen fibers, which at birth can have elongation values of over 50 percent, decreasing to 40 percent in young adults, and

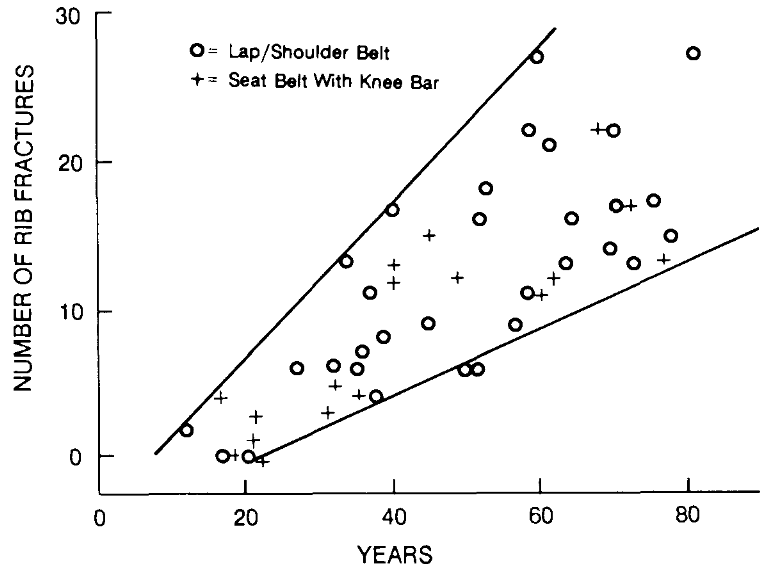


FIGURE 14 Incidence of rib fractures in unembalmed cadavers of different ages restrained by seat belts in sled tests *(12)*.

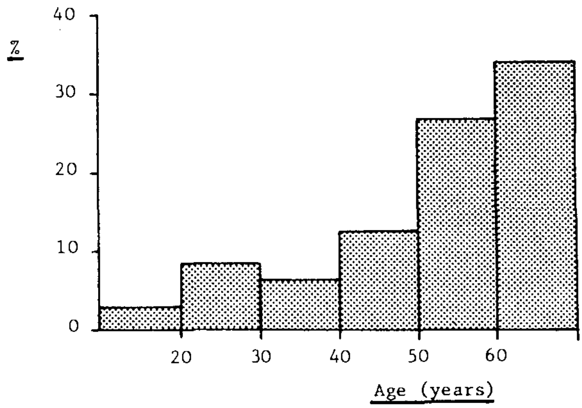


FIGURE 15 Percentage of belt-restrained front-seat occupants in frontal collisions receiving AIS-2+ chest injuries by age *(13)*.

reducing to 25 percent in the elderly. The ultimate strength of the fibers is also reduced with age. As a consequence, joint function and resilience are diminished. Curiously, one biomechanical characteristic that improves with age is the strength of the skin, which shows a marked increase, making it somewhat more resistant to lacerations.

Other changes in the musculoskeletal system occur with age and can have a profound influence on susceptibility to other injuries. One consequence of the aging process is consolidation of the spine; the discs become less flexible and less able to change in water content. Anthropometric data show that from 30 to 65 there is a slow reduction in stature of about 3 cm, due to both compression of spinal disc spaces and changes in curvature of the spine itself. Beyond 65 there is a more rapid reduction in stature of about 10 cm for the next decade. These changes in the geometry of the spine coupled with a reduction in elasticity of the spinal ligaments probably lead to a great reduction in injury tolerance when neck flexion occurs under crash conditions. In severe cases this leads to a greater susceptibility to cord damage.

In addition to these normal aging characteristics, degenerative arthritis is a common pathological condition. The cartilaginous articular surface within joints becomes irregular and is eventually destroyed so that bone-to-bone contact occurs. In itself this is a painful condition, but under impact conditions it may well produce a greater susceptibility to injury when crash loads are transmitted through a joint.

With age the vascular system is also more vulnerable to injury and less adaptable to injury. Atheroma of the arteries is a common feature in older persons, leading to more serious consequences of blood loss and anoxia. This is especially important in traffic head injuries. Similarly, reduced respiratory performance with age means that the body is less able to respond to traumatic shock, and thus the consequences for both respiratory function and brain function are likely to be more serious in older persons for a given injury. Many of these reductions in biomechanical performance are not directly age dependent, but follow more from a life-style of poor diet, lack of exercise, excessive use of alcohol and tobacco, and other aspects of modern (particularly urban) living.

In conceptual terms one may consider there to be a number of populations, two of which are shown in Figure 16. Current knowledge does not allow these populations to be defined quantitatively as yet, and it is likely that there is a substantial overlap for most biomechanical criteria, particularly bone fracture thresholds. In concept, however, it is clear that crash-protective design should recognize that impact tolerance cannot be represented by single point values for given body regions, which is the current practice for regulations governing vehicle crash performance. Current procedures do not yet recognize this concept of populations at risk, the corollary being that for any given crash condition and tolerance value stated, there will always be some proportion of the population who will not be protected.

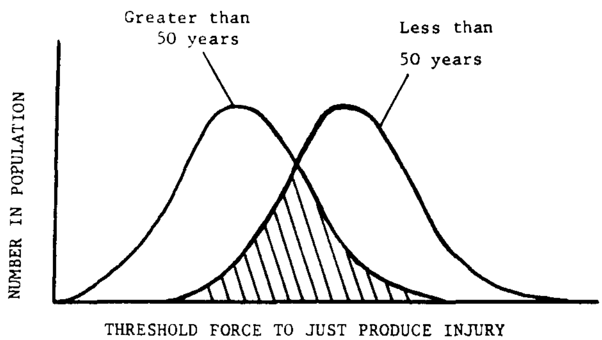


FIGURE 16 Injury tolerance variation for two populations.

Once it is recognized that these population differences exist, optimizing design for certain segments of the general population will become a more realistic procedure. One consequence is that it may be practical to offer optimal crash performance for one end of the population continuum who have both specific biomechanical characteristics and particular exposure parameters in terms of crash frequency, direction, and severity.

OCCUPANT CRASH PROTECTION

Current Practice

Vehicle Occupant Standards

In terms of biomechanical criteria used for assessing crash protection, there are only three parameters in current regulations. These apply to the head, the chest, and the femur, and they only operate in the front-to-back direction; that is, the forces are applied to the front of the head, the chest, and the knees of an occupant sitting in a car as those parts of the body make contact with structures ahead of the initial sitting position.

The Head Injury Criterion (HIC) is supposed to represent a weighted index of the force-time history applied to the head under crash conditions. An acceptable, or tolerable, limit for the index is taken as 1,000, which roughly approximates an acceleration limit of 80 *g* for 3 msec. An HIC of 1,000 was originally meant to indicate a 50 percent chance of survival, but subsequent work has suggested that it represents a head injury of AIS 3 for some 15 percent of the population. There is, however, much debate by experts over how the HIC, as measured in current anthropometric dummies, actually relates to the population at risk. One might suggest conceptually that an HIC of 1,500 might be a satisfactory standard for the population under 40 years of age, but a value of 1,000 is appropriate for those over 60.

The chest requirement is currently a limit of 60 *g* for 3 msec in the front-to-back direction. It is likely that a side-impact standard will be promulgated

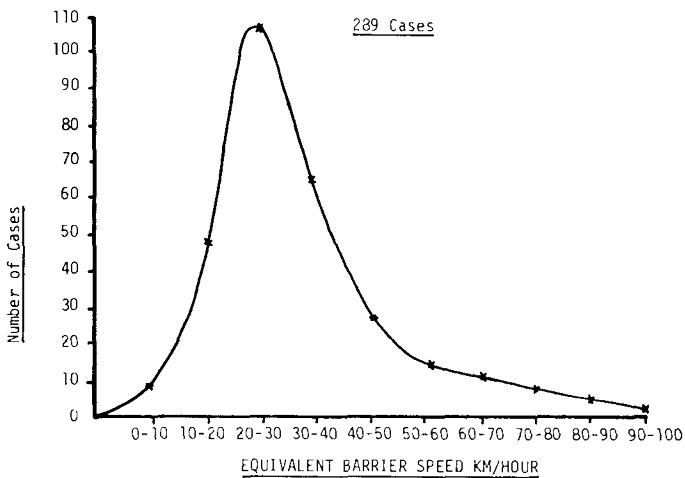


FIGURE 17 Equivalent barrier speed distribution for injury-producing frontal collisions *(3)*.

shortly in which deflection of the chest as measured on a special side-impact dummy (SID) will be used, with a limit of 2 in. for acceptable deflection. The relationship between these thresholds and the incidence of life-threatening injuries in the population at risk is not clear, but even a somewhat arbitrary performance standard represents a start for the side-impact condition.

The femur load is currently set at 2,250 lbf measured in compression of the femur as a result of a knee impact. This is the simplest biomechanical criterion, and it is of interest to explore how a single point requirement such as this femur load limit actually relates to protection levels in the population at risk.

Figure 17 *(3)* represents a typical distribution of frontal collisions that produce AIS-2+ injuries to unrestrained occupants, and Figure 18 represents the likely distribution in threshold force to produce a fracture of the femur for the exposed population. Figure 17 gives the following proportions of frontal collision speeds:

Speed (mph)	*Collisions (%)*
0–9	20
10–18	35
19–30	32
31–48	11
49+	2

Consider two different designs of instrument panel that the knees will strike. The first design provides negligible risk of injury up to 9 mph. For collisions between 10 and 30 mph, it produces an essentially constant load of 1,700 lbf, but for collisions above 30 mph, the structure causes very high loads that injure all of the population. Thus, with such a design the following proportion of riders will be injured:

Speed (mph)	*Collisions (%)*	*Persons Susceptible (%)*	*Persons Injured (%)*
0–9	20	0	0
10–30	67	20	13.4
30+	13	100	13.0
Total			24.4

The second instrument-panel design is also constructed to provide negligible risk up to 9 mph. For collisions from 10 to 18 mph it exerts a load of 1,700 lbf, and for collisions between 19 and 48 mph the load exerted is 2,500 lbf, the limit allowed by the current standards. For collisions over 49 mph it causes injuries to all of those at risk. With such a design the following proportions will be injured:

Speed (mph)	*Collisions (%)*	*Persons Susceptible (%)*	*Persons Injured (%)*
0–9	20	0	0
10–18	35	20	7
19–48	43	90	38
49+	2	100	2
Total			40

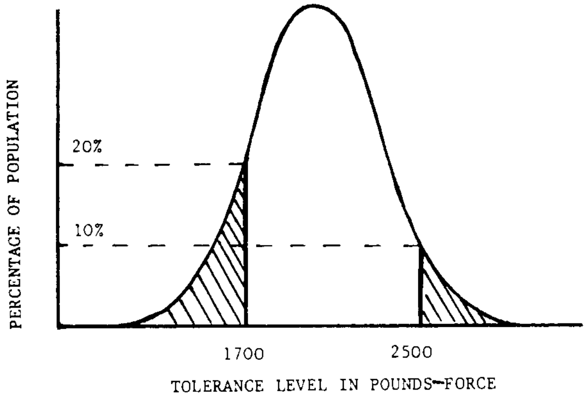


FIGURE 18 Hypothetical lower-limb tolerance level distribution.

This comparison shows that the second design, although it limits loads in higher-speed collisions than the first and would give a better NCAP rating at 35 mph, generates more injuries on an overall population basis. By focusing on providing protection in a relatively small number of high-speed collisions, it generates more injury in the more numerous low-speed crashes among the vulnerable 20 percent of the population.

This realistic, though hypothetical, example shows that recognizing trade-offs in design when populations are exposed to risk is more effective in providing protection than optimizing protection around a single tolerance level for a given crash severity, which is the current practice in the industry because of the way in which the crash performance standards are conceived. Because older persons are at the vulnerable end of the biomechanical spectrum, they have most to gain from a recognition of these factors in terms of future vehicle design.

Besides the three biomechanical performance requirements for head, chest, and femur, there are other regulations that although not actually specifying human tolerance values, do recognize certain biomechanical requirements. For example, permissible seat-belt angles and anchorage positions, head restraint dimensions, and the energy-absorbing characteristics of steering wheels and instrument panels all imply certain biomechanical characteristics.

Virtually all crash types have the skewed distribution shown in Figure 17, in which there are a large number of low-speed events and much fewer at very high energies. Similarly, population responses vary, probably with a classical bell-shaped distribution (Figure 18), although there may well be a considerable tail on the more susceptible side as the proportion of older persons in the population increases.

Given these two interacting distributions it is highly unlikely that any single design can satisfactorily optimize the crash characteristics of the vehicle to effectively prevent both the small number of fatalities to young men and the much larger number of lesser levels of injury to the vulnerable end of the population. To resolve these issues requires a significant research effort, which may result in setting future standards for several different crash severities and several levels of injury severity. Current head and chest requirements are basically aimed at preventing death. Lower tolerance levels could well be specified for protection against less severe injuries.

Seat Belts

The most effective protection system currently available in all cars is the lap-shoulder seat belt. With its universal use approximately 45 percent of all fatal and serious injuries are prevented in comparison with no belt use. Current seat-belt use is around 30 to 50 percent in states with mandatory use laws and 10 to 20 percent in states without such laws. Survey data indicate substantial differences in use rates by age and type of car, newer cars and imported vehicles having higher use rates than older domestic cars. Also there is some suggestion that older occupants have lower use rates than the average. This may be for attitudinal reasons, but there are experimental data to show that some older people with arthritic limitations have great difficulty coping with current seat belts *(14)*. The main difficulties are reaching and buckling the belts, but comfort is also a problem for those of small stature or who are overweight. Solutions to these problems are discussed in the next section.

In terms of crash performance, Figure 15 shows the increasing incidence of rib fractures in the elderly from seat belts. These data are limited to frontal collisions with negligible intrusion, and they suggest that for older people, current belts are not optimal. Methods of improving that performance are available in terms of preloading the seat belt, a technology of particular benefit for older persons, also discussed in the next section.

Head Restraints

Many head restraint designs allow large amounts of angular rotation of the head before its relative motion is arrested. For older people, who have a reduced tolerance to such motion under dynamic conditions, there is an increased injury risk. A redesigned, fixed head restraint, one that does not need complicated and sometimes strenuous adjustment, would be of particular benefit to older persons.

Other Energy-Absorbing Subsystems

Current cars have many internal structures that are parts of the crash-protective package. All of these have energy-absorbing characteristics: the steering assembly, the upper and lower instrument panel sections, the door, the A and B pillars, the header rail, and the side roof rail.

Energy absorption should reflect the nature of the forces that will be applied in a range of crash types and severities and to a range of people exposed to risk. The exposure-tolerance distribution issues outlined earlier for instrument panel design therefore apply to a greater or lesser degree to all of these subsystems. For older persons, an especially vulnerable segment of the population, there are many such structures in current cars that are not optimal.

New Technologies

Restraint Systems

Having been relatively static for a decade, occupant protection is now making major advances. "Passive" restraint requirements for certain specified collision types are being introduced following a recent ruling by the Secretary of Transportation, and for the driver those requirements are being met in many cases with air-bag systems. Such systems, however, are supplementary to lap-shoulder belts. Although air bags may allow a car to pass the legal requirements for occupant restraints, they cannot offer adequate protection in the range of actual crash types. Lap-shoulder belts are still required in rollovers, multiple impacts, side impacts, rear-end collisions, and crashes below the firing threshold of the air-bag sensor. Many people erroneously believe that air bags eliminate the need for seat belts. However, none of the current passive restraint systems, whether air bags or static "friendly interiors," provide acceptable crash protection in the real world of collisions without the concurrent use of a seat belt.

For older persons this is particularly important because of their relative vulnerability. Nevertheless, such supplementary air-bag systems and friendly interiors offer additional protection combined with the conventional lap-shoulder belts, and when properly designed would allow older persons to have the same level of protection as is achieved by the younger population with conventional seat belts alone.

Supplementary Air Bags

The current timetable for the introduction of "passive restraint" automobiles is so phased that by the mid-1990s all new cars will meet the requirements for the two front outboard sitting positions in frontal and angled barrier crash tests at 30 mph.

For the driver the technological response is to provide either a passive shoulder belt and an active lap belt or a supplementary air bag mounted in the hub of the steering wheel together with an active lap belt. The injury criteria must be met in the specified crash tests without the use of the active lap belt. The one major exception is in the General Motors Bonneville line of automobiles, in which a door-mounted lap-shoulder belt is offered. In view of the ease with which such a system can be disconnected, it will be interesting to see the level of use of such a system in practice.

The supplementary air bag has the advantage over a shoulder belt in the more severe frontal collisions because in a velocity change of more than approximately 25 mph, a driver restrained only by a shoulder belt can still have face contact with the steering wheel. The injury-producing consequences of such contacts can be minimized by good design of the hub-and-spoke system of the wheel, but because of the relative fragility of the face in serious collisions, some trauma is inevitable. The supplementary hub-mounted air bag reduces this injury risk by cushioning the head and preventing localized facial load.

There is a further benefit of the hub-mounted air bag for older persons. Investigations of actual collisions show that neck strains and sprains are associated with use of lap-shoulder belts in frontal crashes, particularly for women and older persons. The supplementary air bag reduces the amount of neck flexion that occurs by causing the head and torso to decelerate together. This design will therefore be particularly appropriate for older drivers.

It is likely to be about a decade before air-bag technology is available for front-seat passengers generally. One important issue is the problem of the out-of-position passenger, a more likely occurrence than an out-of-position driver and particularly likely with children. That problem coupled with the greater range of passenger weights and sitting heights and the necessarily larger volume required for a passenger-side air bag (approximately three times the volume in comparison with a steering-wheel-mounted air bag) make the technology more difficult and the benefits more problematic. Only one manufacturer, Porsche, offers a passenger-side air bag as a solution to the passive requirements of Federal Motor Vehicle Safety Standard (FMVSS) 208; all others are currently providing passive belts of various types.

Current research with driver-side air bags shows that many of the myths surrounding air bags are untrue. Air bags do not inflate spontaneously because of malfunctions or minor impacts with curbs and garage doors. They do not present any serious risk to hearing because of noise or overpressure. They do not obscure vision or trap drivers after a crash. The soft nature of the actual facial contacts prevents serious risk to anyone wearing glasses, which is particularly relevant because about 20 percent of older persons wear glasses for driving. No data are available on the consequences of air-bag deployment for cigarette or pipe smoking, but intrinsically such incidences are unlikely to be serious.

It is most important to recognize that cars meeting the passive-restraint requirements of FMVSS 208 with air bags for an otherwise unrestrained occupant do not provide adequate protection in the real world of collisions. As stated earlier lap-shoulder belts or shoulder belts coupled with knee restraints will still be necessary. A study in 1972 *(15)* showed that if lap-shoulder belts were worn by 75 percent of front-seat occupants or more, the overall benefits would be equal to or greater than those generated by 100 percent availability of front-seat air bags for otherwise unrestrained occupants. That prediction is probably still true with current technologies. Hence there is a continuing need to enhance the performance of seat belts and to recognize the specific needs of the older person in this technology.

Air bags necessarily have a threshold crash velocity change below which they cannot be activated. Current sensors are triggered at a velocity change of about 12 mph in the direction of the reticulating axis of the automobile. This means that the fore-and-aft vector of the crash force must exceed that value. As the impact angle diverges from straight ahead a higher crash speed is required for firing. In side collisions, the air bag will not be activated.

The data shown in Figures 5 and 7 give some indication of the incidence of crashes producing varying injury severities that are below the firing threshold for air bags. Current NCSS data show that for a velocity change of 12 mph or less the following percentages of injured occupants are not protected by air bags *(5)*:

- All injured occupants in frontal collisions with $\Delta V < 12$ mph: 56 percent;
- AIS-2+ injured occupants in frontal collisions with $\Delta V < 12$ mph: 21 percent;
- AIS-3+ injured occupants in frontal collisions with $\Delta V < 12$ mph: 13 percent;
- AIS-6 occupants (fatalities) in frontal collisions with $\Delta V < 12$ mph: 5 percent.

For older people, an AIS-2 injury is likely to result in significant reduction in the quality of life; therefore, an injury of this level can be used as a reasonable criterion for significant trauma. On that basis about 20 percent of occupants with AIS-2+ injuries will not be protected by current air-bag technology in frontal crashes.

Frontal crashes represent about 54 percent of all crash types at the AIS-2+ level. Hence, if it is assumed that air bags do not offer significant protection from or are not released in other crash types—side, rear, and rollover—then air bags will only help in some 43 percent of all AIS-2+ crashes. This illustrates the need for the continued use of seat belts.

Enhanced Seat-Belt Performance

Pretensioning of seat belts, offered on some cars already, is a method that can achieve improved protection above that of current belts. The problem shown in Figure 15 can be diminished for older persons by preloading the seat belt and having the belt elongation characteristics specifically tuned to the geometry of the passenger compartment and the crush characteristics of the car. Advanced design should optimize those factors and also recognize the population differences in body weight and acceptable tolerance values for those using such systems.

It is likely that no single design solution can be achieved for all those requirements. Therefore it might well be reasonable to offer a car designed specifically for the vulnerable population, in essence tuned for the population that is small in stature, older, and involved in low-speed crashes. The feasibility of this concept and its likely benefits need to be explored in further research projects.

Ergonomic Aspects of Seat Belts

Although they go beyond crash performance, technologies that encourage belt use and solve the specific problems of older persons are relevant. The widespread adoption of electronics within the vehicle offers greater seat-belt comfort and convenience. Power-assisted positioning of the seat, with memory recall, allows the seat to return to the best position for each occupant. Lower belt mounting points on the seat give optimum lap-belt position regardless of seat adjustment. Similarly, power-assisted adjustment of the upper mounting point with a memory setting diminishes much of the discomfort of belts that reduces their use by older persons. Certainly an adjustable upper mounting point, now common on current models in Europe, is a necessary requirement for acceptable seat belts for those of small stature.

The seat-belt presenter, demonstrated in the Daimler Benz coupe, is a solution for those with such limited joint motion that the rotation necessary to reach the conventional belt is hard to achieve. With more widespread adoption of electronic systems and power assistance, such devices could greatly enhance the acceptance of belts by older persons.

Current research indicates that well-fitting lap-shoulder belts for the outboard rear seats are appropriate for satisfactory crash protection for adults.

Similar standards of crash performance and ergonomics should apply to the rear seats as well as the front; many current rear-seat belts have inferior details. Center rear-seat occupancy is only 1.5 percent, whereas outboard rear-seat occupancy is 10 times greater—around 15 percent. Hence, a case can be made for having only two designated seats in the rear, with many consequent advantages for seat-belt design. Survey data suggest that rear-seat occupants are either the young or the old, and thus improved restraint systems in the rear are a particular priority for older persons.

In general it is clear that seat-belt design is now being integrated into the basic conceptual package of the vehicle. Belt anchorage requirements influence pillar positions, seat design, and interior geometry and only on that basis will satisfactory systems be provided. With the advent of power-assisted electronics for seats and restraints, many of the problems of seat-belt acceptability will be solved. For older persons in particular there is a need for these advances to reach the marketplace.

Other Crash-Protective Systems

Knee Bars

Some passive restraint systems, notably supplementary air bags for drivers and single diagonal door-mounted passive belts, rely on a distinct structure at knee level to decelerate the lower part of the body, which contains about 50 percent of the total body weight.

Design issues of particular importance for older persons are involved in this system. The reduced tolerance to fracture of the elderly has been discussed, but beyond that, there is posttraumatic arthritis, to which older persons are particularly susceptible. Blows to the knee that do not generate fracture at the time can still cause arthritic problems *(16)*. It may be preferable for the older person to have the lower body restrained at the pelvis by a lap belt, thus diminishing the frequency and severity of blows to the knee. The corollary of this approach is that the position of the lap belt becomes crucial, with abdominal injuries occurring if the belt is misused. This is another example of the conflict between crash performance and everyday acceptability. Single diagonal passive belts offer greater convenience and ease of access. It is clear that a number of solutions should be offered and that an educational effort should be made to explain the various advantages and drawbacks of the several systems.

Windshields

Several antilacerative inner coatings are now being developed for laminated windshields that will essentially eliminate facial lacerations under normal impact conditions. Injuries from conventional glass windshields are normally relatively minor, so the added protection from the antilacerative development is not great, and it is not a substitute for such restraints as seat belts or air bags. This technology provides a benefit to all who are unrestrained, but it is particularly important in low-speed collisions in which air bags are fired. In such collisions where the necessary velocity change to fire an air-bag sensor is not mobilized, the unrestrained occupant will hit the windshield with his head. The threshold velocity change for current supplementary air bags is in the range of 12 to 20 mph. Figure 17 suggests that there are many collisions below such threshold levels that will generate injury to unrestrained occupants. For the unrestrained older person, therefore, who proportionally is involved in more low-speed collisions, the antilacerative windshield is particularly appropriate.

THE ELDERLY PEDESTRIAN

The general principles of exterior vehicle design for pedestrian protection have already been outlined. The state of knowledge is such that requirements for the bumper, hood edge, and hood can now be written to provide protection for pedestrians in general. Already many manufacturers have in-house standards for the hood that eliminate hard spots in the head-contact zone and protect the pedestrian from direct contact with the stiff structures at the base of the windshield.

Nonmetallic, plastic, and skinned-foam structures for the integrated nose sections of many cars, although introduced for aerodynamic and styling reasons, provide relatively noninjurious impacts for the lower limbs of pedestrians. The Fiero GT shows what can be achieved without generating conflicts with the no-damage requirements for bumpers.

A case needs to be developed for the likely benefits for older persons from such advances. For the elderly, lower-limb injuries are undoubtedly more serious and more disabling than they are for younger age groups. Serious limb injuries can result in emboli and permanent disability for older people more frequently, and the outlook for total recovery is poor. Even a slight lower-limb injury can markedly reduce in the quality of life in older persons if joint function is impaired or if already arthritic articular surfaces are damaged.

In terms of a threat to life, the elderly are clearly more at risk for the same level of injury, as was shown in Figures 1 and 11. However, because of the absence of any agreed-on disability scale, it is not possible to examine quantitatively the benefits from propedestrian vehicle design. As indicated in an earlier section, these benefits are likely to be substantial, particularly for older persons.

COST-BENEFIT CONSIDERATIONS

Priorities for development of crash-protective design and legislation controlling such design tend to be set by consideration of costs and benefits. There are two separate techniques, one absolute and one relative. Cost-effective comparisons are a reasonable method for deciding on one development rather than another. The savings from additional padding to protect rear-seat occupants in side impacts can at least conceptually be compared with the savings that might come from the provision of head restraints for rear-seat occupants. Such comparisons are internal in the sense that many of the uncertainties about the values to be attached to various types of injuries cancel each other out.

That is in contrast to cost-benefit calculations in which a dollar value for a certain development is fixed against a number of injuries projected to be saved. The cost of introducing that development into the vehicle fleet is then calculated. An equation is written in which the costs are compared with the benefits. The implication is that advances can only be justified if the dollar value of the benefits outweighs the cost of the development. Such a technique can easily be used, and indeed is used regularly by many governments, to justify not introducing certain legislation and design improvements.

However, such a technique is suspect because of the great uncertainties in putting actual dollar values on the consequences of traffic injury. Some of the direct costs are easily quantified, particularly treatment-related costs and loss of earnings. For both fatal and nonfatal trauma, the older person (over 65 years of age) shows somewhat higher treatment costs than younger age groups *(17)*, but substantially lower costs in terms of loss of earnings.

Beyond such tangible costs, however, there are a host of quality-of-life issues that are especially important for older people because of their greater vulnerability and their greater exposure to social deprivation if disabled. Loss of mobility, increased dependence on others, and loss of social contact all have an obvious intrinsic worth that cannot be quantified with current techniques in an agreed-on manner.

In the context of crash performance, all that can be said at this time is that the first generation of crash-protective standards was focused primarily on preventing death. Those standards have had a large measure of success, and now there is a need to address nonfatal injuries and their prevention. Because older people suffer particularly from the disabling consequences of relatively moderate trauma, there is a special interest in developing protection against such injury in relatively low-speed crashes.

Cost-benefit and cost-effective analyses should be able to play a role in developing such protection, but the main difficulty centers on an agreed-on method of quantifying disability and quality-of-life issues for all age groups. This is an area in which specific research is required. As a general observation, it is clear that the potential for enhancing the quality of life by minimizing trauma through effective crash-protective design has not been approached scientifically. The fundamental epidemiological data bases and biomechanical knowledge of human response do not exist at an adequate level for rational and effective preventive health strategies to be introduced. Now that the FMVSS 200 series of standards has been empirically conceived and focused primarily on preventing death, a more Cartesian approach is needed so that more detailed insights into costs and benefits can be made.

CONCLUSIONS

Although superficially it might be thought that, in terms of crash protection, the interests of older persons generally coincide with those of the rest of the population, this review has suggested that, in reality, there are enough differences to warrant a more detailed examination of the specific needs of the older person. These differences arise in four areas: (a) exposure, (b) biomechanics and differing response to injury, (c) occupant crash-protection requirements, and (d) pedestrian protection requirements.

Exposure

Some of the general population characteristics of older persons relate to crash exposure, such as an increasing proportion of women. There are no adequate crash or control data, however, to examine in depth the specifics of crash risk in older persons, mainly because of the absence of discriminating control data on type of driving by environment and time for various age groups.

One may generally conclude that older persons as car occupants are

- More seriously injured for a given crash exposure,
- Hospitalized longer for a given initial injury,
- Exposed to fewer high-speed frontal collisions,
- Exposed to more car-to-car side collisions, and
- Exposed to more disabling injuries, which are predominantly to the head and lower limbs.

For pedestrians, the absence of control data makes it difficult to compare the exposure of older persons with that of other age groups. Once involved in a pedestrian collision, an older person receives injuries more frequently and has more serious and more disabling injuries than younger age groups.

Biomechanics and Differing Response to Injury

This paper shows that older persons have distinctly different responses to injury than younger age groups. A given injury generated by a blunt impact, which is what constitutes virtually all crash loads in both car occupant and pedestrian collisions, will produce more fractures and more serious injury generally, leading to a greater incidence of disability and a greater risk of death in older persons than in younger ones.

In some instances these differences can be quantified. For example, a seat-belt load in a severe collision that produces a single rib fracture in a healthy young man may well produce a flail chest injury in an older person (over 65 years) with attendant risk of major interthoracic trauma, a life-threatening injury. It is clear that for virtually all types of injury a specific tolerance or threshold level of force can be established. That tolerance level varies throughout the population at risk, and the older person probably represents the most vulnerable quartile. The difference between the most vulnerable and the least vulnerable quartiles is not adequately delineated but is likely to be one or two orders of magnitude.

Current crash-protective standards and current industry practice for crash-protective design do not recognize this fundamental variability in tolerance to impact. Standards are conceived as single-point, pass-or-fail criteria. In reality, for any given performance requirement there will always be some proportion of the population who will not be protected. The recognition of this variability is vital in assessing optimum crash-protective design for older persons. There are some specific types of injuries to which older persons are particularly vulnerable, notably neck and spinal lesions in which reduced disc space and osteoarthritic conditions have a direct adverse effect on the mechanisms of injury.

Occupant Crash Protection

To improve the protection of older persons as car occupants, it is necessary to recognize the differences between younger and older persons, both in exposure (i.e., crash type, frequency, and severity) and response (i.e., injury incidence and severity and disability afterwards). In practical terms this would lead to relatively softer internal structures and less injurious car-to-car collisions, with enhanced performance for older persons in relatively low-speed side collisions. Thus a car manufacturer would meet the basic single-point standards as currently required but would then focus his detailed design to enhance protection for the relatively low-speed crash and the vulnerable end of the population at risk. More fundamental standards should be promulgated in recognition of the problem of vulnerable occupants in low-speed crashes.

This leads to the suggestion that the market be explored to see whether this basic fact of human variability can be addressed by perhaps selling several versions of a basic model or, indeed, developing a particular model specifically for the needs and characteristics of older persons.

Because of the vulnerability of older persons, passive restraints are particularly appropriate, both for ergonomic reasons and for crash protection.

Supplementary air bags are especially applicable for older drivers, but really convenient, comfortable seat belts of the passive variety are also necessary, because air bags alone can intrinsically offer protection only in a limited range of crash types.

Pedestrian Crash Protection

This paper shows that older persons may well be overrepresented in pedestrian casualties. Because pedestrians receive head and lower-limb injuries predominantly and because such injuries frequently lead to significant disability in older persons, there is a particular need to introduce propedestrian concepts into vehicle exterior design. In spite of a number of biomechanical uncertainties, enough is known about the desirable characteristics of vehicle front structures to enact a standard for pedestrian protection.

The current non-safety-oriented economic standards that govern bumper design are not necessarily in conflict with the requirements for pedestrian protection. Predictions of the benefits of propedestrian design for all at risk are substantial, and older persons particularly will benefit from such improvements. As current technology for protecting car occupants is introduced into the vehicle fleet, the problem of pedestrian trauma will rise in importance.

RECOMMENDATIONS

From the foregoing discussion, a number of recommendations can be made both for action and for further research. These are outlined in the next two sections as near-term proposals and research and policy development.

Near-Term Recommendations

Near-term recommendations are as follows:

1. Fundamental to the specification of effective crash protection is a recognition of variability among the population at risk. Older persons have a lower tolerance to impact forces. All of the FMVSS 200 series should be reviewed by the National Highway Traffic Safety Safety Administration (NHTSA) of the U.S. Department of Transportation in terms of its effectiveness in protecting the vulnerable end of the spectrum of the population at risk. Assumptions about differences in human tolerance values will have to be made, but at least the principle of addressing population distributions rather than using single-point values should be introduced into rule making and into assessing the effectiveness of such rule making.
2. A side-impact performance standard should be promulgated by NHTSA to address car-to-car crash conditions. That standard should recognize the biomechanical characteristics of older persons in such collisions.

3. Supplementary air bags and passive seat belts are particularly appropriate for older persons. The timetable for the introduction of passive restraints for both drivers and front-seat passengers should be accelerated by NHTSA to encourage the widespread availability of these devices.

4. The comfort and convenience of many current active and passive belts, as well as their crash performance, are not optimal. Manufacturers should pay greater attention to the detailed design of such systems from the point of view of older persons whose joint movements are limited.

5. The application of electronics to seat and seat-belt adjustments should be encouraged. No single, static seat-belt mounting point can adequately provide correct belt positioning for the population using front seats. The lower mounting points should move with the seat and the upper mounting point should be made adjustable on the B-pillar. Passive belts should similarly provide for a range of occupant sizes and seat positions.

6. Air-bag sensors should be developed by the industry to lower the firing levels for both supplementary air bags and preloaded seat belts. Inadvertent firing, although inconvenient, is to be preferred to nonoperation.

7. A propedestrian crashworthiness standard should be promulgated as soon as possible by NHTSA.

8. Disabilities and reduction in quality-of-life factors, although still difficult to quantify, should be used in rule making by NHTSA as has already been done in other cases. The AIS Committee should be supported in its work toward a consensus on a disability severity scale.

Research and Policy Development

Necessary research and policy development are as follows:

1. Biomechanical studies should be supported by appropriate agencies [Centers for Disease Control (CDC), NHTSA] to delineate the population differences in injury threshold values.

2. Manufacturers should examine the feasibility of offering enhanced crash performance for the relatively vulnerable segment of the population at risk in low-speed crashes.

3. Studies should be initiated by NHTSA to delineate the crash exposure differences for the young, the middle-aged, and the older person, and sex differences should also be examined.

4. Coupled with the foregoing studies, control data on driving exposure should be collected for the various populations at risk of sufficient quality to provide controls for the field accident data files of the Fatal Accident Reporting System, NCSS, and other sources.

5. Both exposure studies and field accident studies should be initiated and coordinated by NHTSA and CDC to investigate the risks, causes, and consequences of pedestrian injuries for the various age groups, but particularly for

older persons. Propedestrian rule making should be accurately evaluated so that before-and-after comparisons can be made.

6. Demographic projections by CDC and NHTSA should be initiated to quantify the impact of the increasing population of older persons on the number of traffic casualties generating disabilities and the requirements that those casualties will have for treatment and rehabilitation. The consequences for health resources should be reviewed by the appropriate government agencies.

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