SERIOUS TRAUMA TO CAR OCCUPANTS WEARING SEAT BELTS

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INTRODUCTION

The aim of this paper is not to demonstrate the effectiveness of seat belts, but to discuss in detail some of the factors which compromise their optimal performance and to describe the nature and frequencies of serious injuries sustained by belt users. Many authors (1-6) have shown that the seat belt provides considerable protection for the user in the accident situation, but its efficiency is nevertheless highly dependent on the maintenance of the integrity of the passenger compartment, on the correct use of the restraint system and on the characteristics of the system. By analysing those files compiled by the Accident Research Unit at Birmingham University in which a restrained occupant of a car was seriously injured, some of the features resulting in limited protection have been identified.

THE STRUCTURE OF THE SAMPLE

Since 1969, personnel from the Accident Research Unit have routinely collected data on cars involved in accidents in Birmingham and its environs. Notification of accidents of interest to the research team has always been provided by local police forces. In the early days of the study, one criterion for the inclusion of an accident was that at least one occupant of a car should be what was officially termed "seriously injured". In general terms, this means that the person would be admitted to hospital as an in-patient, having received injuries of at least a severity 2 on the Abbreviated Injury Scale (7). The result of this criterion was that there was an inevitable bias towards crashes involving the more severe injuries.

In order to examine the performance of seat belts, it is necessary to study a wide spectrum of impact severities without regard for the associated injuries at the time of selection. To this end, the accident reporting criterion was modified in 1974 so that all accidents reported to the police in which seat belts were worn were notified to the team. The result of this change will in time make the sample of cases on file more closely representative of the overall picture, but this stage has not yet been reached.

It is thus highly probable that the cases included in this study do not represent a cross-section of serious injury accidents in which a restraint system is used. However, since this paper is aimed at identifying some of the factors which have an adverse influence on seat belt performance by generating injury, the use of a biased sample is acceptable, providing that the conclusions which may be reached are not interpreted as indicative of overall seat belt performance.

The sample of accidents used in this study is comprised of 82 cars in which there were 108 front seat occupants wearing seat belts. All the belts were three point systems except for two single diagonal belts. The distribution of types of belt in the sample is shown in Table 1.

Table 1. Types of seat belt in sample

Type of Belt	Driver	Front Passenger	Total
Three-point static	52	26	78
Three-point automatic	20	8	28
Diagonal static	1	1	2
Total	73	35	108

The types of impacts which the cars sustained are shown in Table 2. As far as possible, the damage to each car was assessed in terms of the most similar crash test configuration. It was however found necessary to include the category "under-run", for which there is no equivalent test, as this configuration of damage has particular importance for restrained occupants.

Table 2. Equivalent test configuration for sample cars

Impact Type		No. of Vehicles
Front	distributed	14
	0 - $\frac{1}{4}$ offset	10
	$\frac{1}{4}$ - $\frac{1}{2}$ offset	10
	$\frac{1}{2}$ - $\frac{3}{4}$ offset	9
	angled barrier	2
	concentrated	2
Side	distributed	10
	sideswipe	4
Rear		1
Rollover		7
Complex		4
Under-run	frontal	8
	side	1
	Total	82

THE INJURIES AND THEIR CAUSES

Injury patterns of the occupants in this sample demonstrate the same multiplicity of injury as is characteristic of unrestrained car occupants. Table 3 shows the frequencies of all injuries and of injuries of different levels of severity. On average, each occupant received injuries to 2.8 body

Table 3. Relative frequencies of occurrence of injuries of different severities by body area, for each restrained occupant (Percentages)

	Abbreviated Injury Scale Rating						
Body Area	1	2	3	4	5	6	All Severities
head	19	30	8	0	5	9	71
neck	8	2	2	0	0	2	14
chest	21	25	6	1	1	10	64
arms	16	14	4	0	0	0	34
abdomen	2	2	1	7	9	1	22
spine (excluding neck)	0	0	2	2	0	0	4
pelvis	10	4	7	0	0	0	21
legs	31	17	17	1	0	0	66

areas. If minor injuries (AIS 1) are excluded, then this figure drops to 2.0 injured body areas per person. Because, as was mentioned above, this sample of accidents cannot be regarded as representative, it is not possible to make a comparison with equivalent statistics for unrestrained car occupants.

The serious neck injuries in this sample were all associated with head contacts and it is of note that even in this sample, biased as it is towards serious injury, no serious head injury was associated with non-contact belt induced head deceleration. The relevance of current injury criteria for the head (H.I.C.) which are applied to those non contact head decelerations must be questioned in the light of this evidence.

Analysis of the types of accidents in which occupants received life-threatening or fatal injuries (A.I.S. 5 and 6) gave an insight into the factors affecting detrimentally restraint system performance. There were 29 people in 27 vehicles in this analysis. In each case, an assessment was made of what single factor, if any, resulted in the injuries received. The factors are listed in Table 4 with the number of times which they occurred. Each of these compromising factors is examined below in more detail.

Table 4. Factor affecting seat belt performance in fatal and severe accidents

Compromising factors	Number of cases
Intrusion - under-run	6
- side	3
- frontal	1
- roof	1
- external object	1
Rollover in soft-top car	2
Excessive load on belt due to rear loading	4
Fire	4
Incorrectly positioned belt	7

INTRUSION

Fundamental to the idea of vehicle occupant restraint as a means of minimising injury is the maintenance of the integrity of the passenger compartment. As can be seen from Table 4, the principal cause of major injury, resulted from the car's own structure deforming into the passenger space. Associated with this problem is the failure to provide adequate protection during rollover accidents in soft-top cars.

The under-run accident is a particularly difficult problem for the car designer to solve alone. Of the 11 occupants in this sample who experienced accidents of this type, 6 received fatal or life-threatening head or neck injuries and 4 sustained a lesser degree of head injury. In the sample of accidents as a whole, only 51 percent of the occupants suffered head injury of A.I.S. 2 or above. In accident configurations other than under-runs, only 10 percent of the occupants sustained head or neck injury of A.I.S. 5 and above. Heavy goods vehicles were involved in all but one of the accidents to the 11 occupants described above. This sample reflects the extreme hazard to car occupants offered by high level loading from H.G.V.s. Many such accidents may involve quite moderate collisions energies which could be safely dissipated if only the heavy goods vehicles involved had some means of loading the stiffest parts of passenger cars, thus avoiding the massive roof level intrusions seen at present. This problem of vehicle under-run is not, of course, confined only to belted occupants.

Apart from the very serious consequences of intrusion as a result of under-run, it is not uncommon for there to be intrusion as a result of side and frontal impacts of the car to car type. Table 4 shows that there were 3 fatalities in side impacts out of 15 such accidents in the sample. The predominant injury in these 3 fatalities was massive chest injury due to contact with the intruding door, accompanied in 2 cases by fatal head injuries caused by contact with the other vehicle.

In 28 cases in addition to the under-runs and side impacts, intrusion was considered to have played a part in the generation of injury for the restrained occupants, particularly to the lower limbs, where footwell disruption and facia displacement still represent serious threats of injury to belted occupants.

EXCESSIVE FORWARD MOVEMENT

This study is based on detailed examinations of the cars involved, where contacts with the interiors are correlated with the injuries sustained by the occupants. Eighteen cases were identified where excessive forward movement resulted in injuries classified as A.I.S. 2 or greater in severity. The type of belt and its function in each collision is listed in Table 5.

Table 5. Belt function associated with excessive forward movement

	Type of Belt	
Belt Failure	Static	Inertia Reel
Centre stalk broke	1	0
Belt broke	3	1
Mounting failed	1	0
Excessive slack in wearing	4	n/a
Reel broke up	n/a	1
Belt reeled out completely	n/a	3
Excessive reel out	n/a	4
Total	9	9

It will be recalled that the total sample consisted of 80 static belts used, and 28 inertia reel belts used. Table 5 therefore suggests that excessive forward movement is very dominantly a characteristic of inertia reel belts.

In the past, two general arguments have been put forward in favour of inertia reel belts. Firstly, static belts are supposedly worn with excessive amounts of slack(9). Our data suggest that although this may well be the case, it has only actually led to injuries greater than A.I.S. 2 in four instances. Again it has generally been supposed that inertia reel belts eliminate this disadvantage of the static belt. The data in Table 5 suggest that in reality, inertia reels are in fact introducing more problems than they solve. In particular the cases, if examined in detail, show that the unbraced passenger is particularly vulnerable if pre-impact braking takes place at a deceleration level below the vehicle sensitivity of the reel. Also a number of complete reel out cases are shown in Table 5 where no load has been taken by the belt at all until all of the webbing was off the reel.

If it is accepted that the major advantage of an inertia reel system in a collision is to eliminate slack, then the data suggest that present day systems are not doing that satisfactorily. Analysis of this sample indicates that even with static belts as worn, inertia reel belts are allowing at least as much, if not more forward movement as is observed with static systems. As for those cases where the inertia reels have either locked up late or failed to lock at all it would seem that urgent consideration should be given to the adequacy of current standards and designs. It would be useful to know if the results of laboratory tests also demonstrate this type of failure of inertia reel systems. These findings would seem particularly worrying with the present trend for manufacturers to offer such belts as the only option and some countries legislating for the compulsory fitting of such belts. No mechanism for such failure can be certainly identified at the moment and it is believed that this is the first time such problems have been cited in the literature.

It should, however, be stressed that although the field evidence appears to raise some serious questions concerning the degree of protection offered by inertia reel systems, their use is still clearly indicated to be beneficial. The discussion is simply whether inertia reel belts, as currently designed, offer as much restraint as static installations, and also how the performance of belts, as a whole, can be improved.

The second general argument in favour of inertia reel belts is that they are worn much more frequently. Certainly data collected in Britain up until 1972 suggested higher usage rates for inertia reels (10). However until recently inertia reels were an optional extra for which the first time buyer made a choice to spend extra or not. Now most U.K. manufacturers fit inertia reels as standard equipment and, as illustrated by Table 6, usage rates between static and inertia systems show no significant differences.

Table 6. Usage rates for belts in Spring 1975

	City Centre	Rural	M-way
	(N = 689)	(N = 673)	(N = 636)
Static	21.8%	44.0%	51.5%
Inertia Reel	23.3%	44.0%	57.5%
Overall	22.2%	44.0%	53.0%

It would appear therefore in retrospect that the high usage rates obtained in the past with inertia reels were due to the first time buyer being atypical. Now that all buyers must have inertia reels (broadly speaking) the apparent superiority of reels has disappeared.

In summary therefore the collision performance of present day inertia reels appears to be unsatisfactory, and it therefore seems vital that their specification should be made more realistic, and the availability of static belts should be encouraged in the interim.

BELT INDUCED INJURY

Before the introduction of the legislation requiring a seat belt to be so designed that it could be engaged using one hand, it was very easy for the unwitting user to wear a belt in a manner likely to generate injury in the event of a frontal impact. The area most vulnerable to incorrect belt positioning is the abdomen and any belt loading over this region appears to offer the risk of serious injury. Very little information has been published on correct belt positioning and it would seem important that future publicity should stress this point.

The locations of the injuries of A.I.S. 2 and over produced by the belts for 30 occupants in the sample are shown in Table 7. For half of these

Table 7. Numbers of body areas sustaining seat belt induced injury by severity

	Abbreviated Injury Scale					
Body Area	2	3	4	5	6	All Severities
chest	16	5	1	1	4	27
abdomen	1	1	4	5	2	13
pelvis	2	1	0	0	0	3

occupants, it was possible to give the causes for the presence of a belt induced injury, as shown in Table 8. The importance of the correct positioning of the seat belt over the pelvic region rather than the abdomen is

Table 8. Causes, where known, of belt-induced injuries

Cause of injury	No. of occupants
Belt worn slack	4
Belt positioned incorrectly	7
Rear loading by other occupants	5

clearly illustrated by close examination of the 7 cases of injury severities A.I.S. 5 and 6. In none of these cases did the user suffer rear loading and in only one case was there severe accompanying chest injury which might have suggested high load. (Even this latter case was only assessed as being equivalent to a frontal distributed barrier collision at 20 - 25 m.p.h. and the injuries to the chest were attributed to the belt being worn slack).

REAR LOADING

The adverse effects on restrained front seat occupants of rear loading by large masses in the rear of the car - not necessarily passengers but possibly heavy luggage or animals - follows naturally from the above consideration of belt-induced injuries. Current designs of front seat are seen to fail without loading from behind in many cases and even the current Federal Standard requiring that a seat should withstand twenty times its own weight offers no protection in a crash against an unrestrained rear passenger.

In 4 of the 5 instances of life-threatening and fatal belt induced chestinjury in Table 8, there was rear loading and seat failure. In total, 27 front seat occupants in the sample experienced loading either from their seat alone or together with a rear occupant.

A solution to this problem is to legislate for rear seat restraints to be fitted and compulsorily used as now exists in Australia and other countries. To insist only on compulsory front seat belt use does not provide as much protection as is potentially available for those using such belts.

FIRES

Seven belted occupants in this sample were involved in collisions in which their vehicles caught fire post impact. The whole problem of post collision fires has been considered in more detail recently (11) and detailed examination of these cases will not be undertaken here. However, consideration of all fire cases on file at the Accident Research Unit, does indicate that the belted occupant, generally, is more likely to be conscious and uninjured post impact than his unbelted counterpart, and thus is more likely to be able to escape from his vehicle in the usually short time from impact to all enveloping fire.

CONCLUSIONS

1. No serious head or neck injury has been seen without direct contact and thus present injury criteria applied to belted dummies which considers the whole duration of the deceleration pulse should be reviewed. For the restrained driver, face contact with the wheel is the rule, and there is a need for injury criteria to be developed to cope with this situation.

2. Intrusion into the passenger compartment is the most frequently occuring compromising factor to belt performance in the present sample.

3. Incorrectly positioned belts represent a particular threat to the abdominal area.

4. Inertia reel belts are seen to allow more occupant movement than occurs with static belts, as worn.

5. Wear rates of static and inertia reel belts do not appear to be significantly different , if such belts are provided as standard.

6. Standards controlling the performance of inertia reel systems should be urgently considered in view of the presence of several cases of late lock up or no lock up within this sample.

7. The unrestrained rear occupant can greatly increase the severity of a belted front seat occupant's injuries. The provision and use of rear seat belts are essential if maximum protection is to be available to the front seat occupant.

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