The Potential for Further Development of Passive Safety

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ABSTRACT - In Europe, emphasis is being transferred from injury prevention to accident prevention to reduce road casualties. This study attempted to identify the current potential for serious casualty reduction using passive safety by examining the crash performance of new cars with seriously injured occupants. The Co-operative Crash Injury Study conducts in-depth investigations of around 1200 vehicles per year from seven sample regions around England. Attention was focussed on passenger cars manufactured from 2004 to 2008 with at least one occupant injured to AIS level 3 or more. 28% of MAIS 3+ occupants were unbelted and 40% were belted but involved in crashes with limited potential for passive protection. A further 32% of occupants were belted and involved in crashes *with* potential for improved crashworthiness design. For these occupants, five major functional requirements were identified for crashworthiness improvement: a reduction of seatbelt loads on the chest and abdomen in frontal crashes, particularly for seniors; reduction in femur and tibia loads in frontal crashes; provision of head and chest protection in near-side crashes; and reduction of occupant lateral excursion in far-side impacts. Together these functions accounted for 70% of the identified requirements. Other smaller requirements were identified, each contributing up to 5% of total. Overall, the case supporting further developments in passive safety still appears significant.

INTRODUCTION

Following continual increases in traffic casualties, the first European crash test requirements were introduced in 1973 (UNECE Reg. 12) to mandate a minimum level of occupant protection in frontal impact. It was soon realised however that fatalities and serious injuries were still occurring in large numbers on European roads, despite the additional introduction of seatbelt legislation in many countries. By the mid 1980s, the UNECE had developed a new frontal crash test which claimed to produce more realistic loading to vehicle structures and included anthropometric test devices to assess injury risk (UNECE Reg. 94). This test did not become the current EU frontal impact directive. Real-world and laboratory research had shown that it did not test the vehicle structure severely enough to mimic the crash conditions associated with serious and fatal injuries in real crashes (Hobbs, 1992). Instead, an offset impact test (EU Directive 96/79/EC) was adopted for new-model cars in 1996 and for all cars in 2003. The EU side impact test directive (EU Directive 96/26/EC) was also introduced in 1996 to address occupant protection in lateral impacts. On the back of the new directives, the European New Car Assessment Programme (EuroNCAP) was launched (Hobbs et al. 1999), providing additional and higher speed assessments of crashworthiness and publicly available safety rankings for consumers. All of these measures have improved vehicle structural performance and encouraged the proliferation of airbag restraints and better seatbelt systems. The net result has been good casualty reductions in real crashes (Frampton et al. 2002). Unfortunately, EU statistics show that around 40,000 fatalities still occur annually on its roads, about half being car occupants, and there is uncertainty about meeting European casualty reduction targets for 2010. In order to address casualty figures, there is now increasing emphasis on crash prevention with a reduction in support for further crashworthiness improvements, based on the assumptions that it would be complex or costly and address only small numbers of casualties. The aim of this study was to shed further light on these assumptions by examining the crash conditions related to injuries of AIS 3 and above in recent model cars, examining the potential for prevention of AIS 3+ injury with further development of passive safety countermeasures.

METHOD

Crash injury data from the UK Co-operative Crash Injury Study (CCIS) were interrogated on a case by case basis using visual examination of case materials. This offers an accurate method of identifying the subtleties associated with injury causation in modern vehicles. The CCIS study selects passenger cars for investigation using a stratified sampling procedure based on maximum injury severity. It includes crashes involving towed cars less than seven years old at the time of the crash in geographical regions selected to represent urban and rural roads in Great Britain (Mackay et al. 1985). In those regions, the study aims to cover all police-reported serious and fatal injury crashes.

The database contained limited information on the accident circumstances but detailed information on vehicle crash severity, structural performance and restraint performance together with photographic documentation of the vehicle exterior and interior along with forensic evidence relating to injury causation. Detailed information was available for occupants, including seatbelt use, age and seating position. Injury outcome was recorded using the Abbreviated Injury Scale (AAAM 1990). Detailed injury information was available for each occupant in the study including maximum AIS by body region and Maximum Abbreviated Injury Score (MAIS). Fatally injured occupants were additionally documented with post-mortem information, a requirement for accidental death in the UK.

A sample of passenger cars produced in years 2004 to 2008 were selected provided that at least one occupant died or sustained injuries of AIS 3 severity or above. The selection resulted in 157 vehicles containing 184 occupants. Adequate photographic documentation or information about seatbelt use was not available for eight occupants (4% of the sample) and these were dropped from further analysis. Initial filtering of data was carried out on the basis of seatbelt use. Non-belted occupants were placed into one category, belted into another. Belted occupant cases were reviewed in detail to determine whether there was potential for reducing the severity of AIS 3+ injury with further passive safety development. The baseline for assessing this potential was the accident itself, with the actual vehicle, occupant and impact, compared to the same accident on the counterfactual hypothesis that its passive safety systems were optimal. This determination required the development of a set of guidelines, i.e. an expert protocol, that could be applied to each case. AIS 3+ injury mechanisms were also scrutinized in order that functional requirements for the prevention of injury could be assigned. The expert protocol rated passive safety potential at three levels: probable, possible and limited. A "probable" rating signified that serious injuries occurred well within the crashworthiness design envelope and there remained considerable scope for passive safety development. A "possible" rating indicated that passive safety potential was established but with a lower level of confidence. A "limited" rating was applied in cases where there was clear doubt concerning the possibility of passive safety protection. The main guidelines used for each rating are shown below.

"Probable" rating criteria

- Crash severity not exceeding those used in standard crash tests
- Standard application of impact force in a horizontal plane
- Typical impact to passenger car, crash barrier or pole/tree
- Intrusion not exceeding that seen in standard front and side impact tests; in far-side crashes, not past midpoint of vehicle.

"Possible" rating criteria

Similar criteria to "probable" rating but with one or more confounding factors:

- Oblique frontal crash
- Swiping impact to front or side
- Frontal intrusion, while not extreme, exceeding that in frontal tests
- One major impact with several minor impacts–occupant possibly out of position (OOP)
- Simple rollover
- Minor underrun component.

"Limited" rating criteria

- Excessive crash severity
- Non-standard application of impact force
- Multiple rollover with several impacts, in different directions, or with major impacts to different sides of vehicle
- Major underrun of vehicle structures
- Intrusion far exceeding that seen in standard front and side impact tests; in far-side crashes, past midpoint of vehicle
- Unverifiable occupant body region kinematics, especially upper limb injury.

No selection of a few cases can adequately reflect the diversity of accident circumstances, occupant characteristics and injury mechanisms seen in a large study such as CCIS. The following cases are intended to illustrate the rating criteria in operation, without claiming to be representative of the whole group of accidents considered in the Results section below. It should be noted that the driver is seated on the right-hand side of these British vehicles.

Case 1. Probable benefit (83 y.o. front pass.)

Case 1. The nature and severity of this head-on impact is within a reasonable design envelope for occupant protection. While the injured front passenger is elderly, it is considered that there is potential for an optimal restraint system to hold injuries below the MAIS 3+ level.

Case 2. Probable benefit (30 y.o. driver)

Case 2. This vehicle underran its collision partner, tending to exaggerate the visible appearance of external damage. There was no intrusion into the passenger compartment. The underrun probably lengthened the duration of impact (compared to full vertical engagement) but may have disrupted the timing of the airbag. It is considered that optimal secondary safety could have held injuries below MAIS 3+.

Case 3. Possible benefit (35 y.o. driver)

Case 3. An oblique impact, not excessively severe, with some intrusion on the left passenger side. The movement of the driver's head was not well controlled by the restraint system. While it is by no means inevitable that this type of impact should result in life-threatening MAIS 3+ injuries, it falls between current regulatory and consumer tests, being neither frontal nor side. In addition, both the head and lower limb were seriously injured. It was assigned to the intermediate 'possible' benefit category.

Case 4. Possible benefit (37 y.o. driver)

Case 4. The roof of this vehicle has been cut over the B-pillars by emergency services. No rollover, but several impacts of modest severity off the road with MAIS 3+ injuries to the head and chest. The multiple impacts may have resulted in deployment of the seatbelt pretensioner and airbags (front and side) before the optimal moment or have brought the driver out of position at the moment of deployment. While not extreme, there is an element of doubt about whether this accident falls within a fair design envelope for occupant protection and so it was assigned to the 'possible' category.

Case 5. Limited benefit (52 y.o. driver)

Case 5. A pole impact on the driver's side, similar in location and direction of force to the EuroNCAP test, but considered to be more severe. Categorised as 'limited' (or no) potential for reducing injury severity below MAIS 3 through improved passive protection.

Case 6. Limited benefit (67 y.o. driver)

Case 6. An offset frontal impact with significant intrusion. Analogous in some ways to the EuroNCAP frontal test but considered too severe and so placed in the 'limited' group.

RESULTS

Passive Protection Potential

176 occupants formed the basis of examination for passive protection potential (PPP), in other words, the possibility of reducing the severity of AIS 3+ injuries. Table 1 shows the level of PPP derived from application of the expert protocol.

Table 1. Passive Protection Potential (PPP)

Passive Protection Potential	Occupants N	%
Unknown - unbelted	49	28%
Probable – belted	39	22%
Possible – belted	17	10%
Limited – belted	71	40%
Total	176	100%

The sample consisted of 72% belted and 28% unbelted occupants. The unbelted group of 49 occupants were not reviewed in detail, so their PPP was not determined by in-depth examination. 40% of the sample were belted occupants where limited potential for protection existed while 32% of the sample were belted occupants who had protection potential. Of these, the PPP was established with a high degree of confidence for 70% and with a lesser degree of confidence for 30%. Of all belted occupants, 56 of 127 (44%) were identified with potential for passive protection. Applying this ratio to the unbelted occupants would mean that, were they all to be belted, then a further 22 of 176 (13%) of the whole sample would have protection potential.

Crash Event and Passive Protection Potential

The crash event is useful information to indicate the type of active safety technology that might be employed for crash prevention, particularly in the cases where there is limited scope for injury mitigation through improved secondary safety. The in-depth data recorded basic crash event information for every occupant. Table 2 shows how the crash event relates to PPP.

Table 2. Crash Event vs Passive Protection Potential (N=176 occupants)

	Passive Protection Potential			
Crash Event	Unbelted	Probable	Possible	Limited
Loss of control-SVA	30	10	5	30
Loss of control	5	4	3	7
Lane departure-SVA	6	1		5
Lane departure	2	8	5	7
Same direction	2	7		9
Junction	3	8	3	8
Unknown	1	1	1	5

SVA denotes single vehicle accident

The majority of events involved loss of control, accounting for 94 of 176 occupants (53%). Events where no loss of control was specified but the vehicle departed from its travel lane accounted for 34 of 176 occupants (19%). Events where car-to-car crashes occurred between vehicles travelling in the same direction occurred for 18 of 176 occupants (10%) and 22 of 176 occupants (13%) were involved in junction crashes. Loss of control occurred for 71% of unbelted occupants, 36% of belted occupants with probable PPP, 47% of belted occupants with possible PPP and 42% of belted occupants with limited PPP.

Belted Occupants with Passive Protection Potential – Impact Configurations

Since European crashworthiness design is optimised for belt use, it is especially important to consider belted occupants where a PPP exists. Table 3 illustrates the impact configurations for belted occupants where PPP was identified.

Table 3. Impact Configurations

Impact	Occupants N	%
Frontal	36	64%
Near-side	10	18%
Far-side	7	12%
Rear	1	2%
Rollover	2	4%
Total	56	100%

The majority of belted occupants with PPP were in frontal impacts. Side impacts were the next largest category at 30%. Far-side impacts featured in 41% of side crashes. Rear impact and rollover did not feature frequently as candidate impacts for crashworthiness improvement.

Belted Occupants with Passive Protection Potential – Frontal Impact

In frontal crashes, each occupant was categorised according to the major crashworthiness issue associated with AIS 3+ injury. Table 4 shows the distribution.

Table 4. Crashworthiness Issues

Crashworthiness Criteria	Occupants N	%
Seatbelt loads	19	53%
Compatibility	3	8%
Excessive neck loads	2	6%
Luggage loads	4	11%
Facia loads	8	22%
Total	36	100%

Seatbelt Loads. 19 occupants were identified with MAIS 3+ solely with chest and abdominal injury caused by seatbelt loading. Their median age was 76 years and 11 of 19 (58%) were female. In terms of seating position, 5 of 19 (26%) were drivers, 9 of 19 (47%) were front seat passengers and 5 of 19 (26%) were rear seat passengers. Rear seat passengers, with a median age of 19 years, were generally younger than those in the front seat. A breakdown of AIS 3+ chest/abdominal injury detail for all 19 occupants is shown in Table 5. The number of occupants does not add up to 100% because some occupants sustained more than one injury type.

Table 5. AIS 3+ Chest/abdominal Injury

Chest/abdominal Injury	Occupants N	%
Rib fracture	13	68%
Pneumothorax	8	42%
Haemothorax	6	32%
Other chest internal	8	42%
Abdomen internal	5	26%
Lumbar spine	1	5%

Rib fracture was clearly the most common injury. Five occupants (about a quarter) sustained serious injury to the internal organs of the abdomen of which 4 of 5 were seated in the rear seats. The occupant who sustained a serious lumbar spine injury was also seated in the rear. In the rear, 4 of 5 occupants did not sustain serious chest injury. One rear seat occupant sustained both chest and abdominal injuries. She was female and aged 79 years. All rear seatbelts were 3-point lap-and-diagonal designs.

Compatibility. Three drivers were involved in frontal crashes which involved underrun of the vehicle structures during impact to trucks. All three sustained AIS 3+ chest injuries associated with the seatbelt. They were classified separately, however, because of the inherent instability of the vehicle structures due to underrun. In one vehicle there was some steering wheel upward intrusion, in another there was direct truck impact to the driver A-pillar though not resulting in a head injury. Engineering design to enable the structures to dissipate kinetic energy were considered the first level of importance here.

Excessive Neck Loads. Two occupants sustained severe accelerative loads to their necks. One 50-year-old male driver sustained a fracture through the left pedicle of the C5 vertebral body. A second 69-year-old female front passenger sustained a fractured facet at the C2 level and an unstable fracture of the right lamina of C2. She also sustained rib fracture and bilateral haemo-pneumothoraces from seatbelt loads. The neck injuries here suggest the possible optimisation of restraints to not only reduce serious chest injury but those to the neck as well.

Luggage Loads. Four occupants were loaded from behind by luggage in the vehicle. Two rear seat occupants with serious head and chest injuries were in a car where luggage behind the rear seat overloaded the seat catch mechanism. One driver was loaded from behind when the equipment in his delivery van overloaded the load partition which impacted the rear of his seat. He sustained a serious chest injury. The fourth occupant was a driver loaded from the rear by heavy bags of compost carried on the rear seat. He sustained two tibia fractures, a right femur fracture and fractured ribs with pneumothorax.

Facia Loads. Eight occupants sustained AIS 3+ lower limb fracture as their only AIS 3+ injuries. Seven were drivers and one was a front seat passenger. Five occupants sustained a femur fracture only, two occupants sustained a tibia fracture only and one occupant sustained femur and tibia fractures (Table 6). All were involved in crashes with little or no intrusion of the vehicle facia and footwell.

Table 6. Lower Limb Fracture

Lower Limb Injury	Occupants N
Right femoral shaft fracture	3
Right femoral condyle fracture	1
Left femoral shaft fracture	2
Right tibia fracture	2
Left tibia fracture	1

Belted Occupants with Passive Protection Potential – Side Impact

Seventeen belted occupants were identified with PPP in side impact. Ten were sitting on the near-side and seven on the far-side.

Near-side Occupants. Table 7 and Table 7a illustrate the body regions injured to AIS 3+ for near-side occupants together with their associated crash conditions.

Table 7. Near-side Injuries and Crash Conditions

		Relevant Airbag			
Sitting position	Object Struck	Head AIS 3+	Chest AIS 3+	Near-side Intrusion	Far-side Occupant Interaction
Front L	pole	yes	yes	minimal	none
Driver	van			moderate	no occ.
Driver	bridge		yes	minimal	no occ.
Rear	wall			minimal	none
Driver	truck			minimal	minimal
Front L	wall			minimal	none
Driver	car			minimal	no occ.
Driver	car	yes*		none	no occ.
Driver	tree			minimal	no occ.
Rear	car			moderate	no occ.

Notes: yes* denotes present but not deployed

Table 7a. Near-side Injuries and Crash Conditions

		No Relevant Airbag				
Sitting position	Object Struck	Head AIS 3+	Chest AIS 3+	Pelvis AIS 3+	Near-Side Intru-sion	Far-side Occ. Inter-action
Front L	pole				min.	none
Driver	van			yes	mod.	no occ.
Driver	bridge	yes			min.	no occ.
Rear	wall		yes		min.	none
Driver	truck	yes			min.	minimal
Front L	wall	yes	yes		min.	none
Driver	car			yes	min.	no occ.
Driver	car				none	no occ.
Driver	tree	yes			min.	no occ.
Rear	car		yes		mod.	no occ.

Eight of the ten occupants were in the front seating positions while two were in the rear seats. Six of the ten occupants sustained serious head injury, five of whom had no head airbag protection. Of the six occupants with head injury, five impacted their heads on the struck object, including the occupant with a deployed head curtain. Five occupants sustained serious chest injury, three of whom had no thorax airbag. Two occupants sustained pelvic fracture and in neither case was a thorax bag present. In all cases, relevant side intrusion was at or below the level observed in EuroNCAP tests. Interaction with far-side occupants (all of whom were belted here) was not a factor in injury causation.

Far-side Occupants. Table 8 illustrates the body regions injured to AIS 3+ for far-side occupants together with their associated crash conditions.

Table 8. Far-side Injuries and Crash Conditions

Sitting position	Object struck	AIS 3+ injury	Injury impact	Far-side intrusion	Excess occupant movement
Driver	SUV	head	windscreen header	minimal	yes
		leg	central tunnel		
Driver	tree	chest	near-side occupant	To 1/4 vehicle width	yes
Rear	wall	chest	near-side occupant	minimal	yes
Driver	car	head	far-side door	To 1/4 vehicle width	yes
		chest	far-side door		
Driver	car	chest	near-side occupant or seat back	To 1/4 vehicle width	yes
Front L	truck	chest	centre arm rest	minimal	yes
Rear	car	chest	Seatbelt	minimal	no

Two of the seven occupants sustained serious head injury but the majority, six, sustained serious chest injury. In six cases there was excess movement across the car, while in one case, an oblique side impact, the seatbelt correctly restrained the 73-year-old female but imparted excess load to her chest. In three cases, interaction with a near-side occupant resulted in serious chest injury. In those three cases the impact was perpendicular to the longitudinal axis of the car and diagonal belt restraint (and hence belt-to-chest loads) was judged to be minimal.

Belted Occupants with Passive Protection Potential – Rear Impact

Only one occupant sustained serious injury in a rear impact. The 52-year-old driver was in a car struck in the rear by another car. This impact was not high severity (39 km/h EES). The driver sustained cervical spine strain and fractures of the 2nd and 3rd thoracic vertebrae. In the absence of any additional loading these injuries were judged to have been caused by extension/flexion of the upper spine.

Belted Occupants with Passive Protection Potential –Rollover

Two occupants sustained serious injury during rollover from partial ejection. In the first case the vehicle left the road, tripped and rolled over some farm machinery. The driver sustained serious head injuries from head contact on the bailing machine despite the presence of a deployed side head curtain. In the second case, a vehicle rolled after clipping a car during an overtaking manoeuvre. The driver suffered a right radius and ulna fracture with degloving when his arm was ejected through the side window aperture. No side curtain was present.

Functional Requirements for Improved Belted Occupant Protection

In order to downgrade AIS 3+ injuries to lesser severities, detailed consideration of occupant injury tolerance, crash conditions and injury mechanisms suggested a number of possible functional requirements for either existing or new passive safety countermeasures. These requirements are shown in Table 9 as a percentage of belted occupants with passive protection potential.

Table 9. Functional Requirements for Improved Passive Protection

Functional Requirement	% of Belted Occs with PPP N=56
Front impacts – belted occupants	
Reduce belt loads on chest esp. for seniors (front belts)	25%
Reduce belt loads on abdomen (rear belts)	9%
Prevent underrun in car to truck impact	5%
Reduce neck acceleration	4%
Strengthen load partitions	5%
Educate users to place loads behind load partition	2%
Reduce loads to femur and tibia	14%
Near-side impacts – belted occupants	
Optimise existing head/chest airbags	5%
Reduce pelvis loading	2%
Provide ride down for head/chest	11%
Far-side impacts – belted occupants	
Reduce lateral occupant excursion	11%
Reduce belt loads on chest for seniors	2%
Rear impacts – belted occupants	
Control extension/flexion of thoracic spine	2%
Rollover – belted occupants	
Optimise existing head curtain	2%
Prevent partial ejection of limb through side window	2%

DISCUSSION

In Europe, emphasis has shifted toward crash prevention in order to reduce traffic casualties. This study aimed to determine the remaining scope for the prevention of AIS 3+ injuries using passive safety countermeasures (crashworthiness). A representative sample of British crashes involving occupants with AIS 3+ injury in modern cars was interrogated. The research looked for passive protection potential against AIS 3+ injury using an expert protocol developed for this study.

The results showed that 40% of MAIS 3+ occupants were belted but involved in crashes where it was not reasonable to expect protection against serious injury. These were generally high severity crashes with passenger compartment collapse. 32% of occupants were belted and involved in crashes with potential for improved crashworthiness design. They were generally in low to medium severity crashes with intrusion similar to or lower than that observed in EU regulation crash tests. Getting more occupants into seatbelts is still a primary requirement for improved passive protection even in the UK where front seatbelt use has been consistently over 90% since the introduction of the seatbelt law in 1983. 28% of the sample consisted of unbelted occupants. These were not examined in depth but the number with passive protection potential (once belted) was estimated based on a belt effectiveness figure of 44%. The proportion of seriously injured occupants who might benefit from passive safety was therefore raised another 13% to a possible 45%. In other European countries, with lower belt usage, the importance of belt reminder systems could be even greater.

It is interesting to compare the estimates of effectiveness for active safety technology against the possible benefits of improved crashworthiness design. Forthcoming European legislation will mean that by 2011, all new-model cars will be fitted with electronic stability control (ESC) designed to address loss-of-control crashes. ESC, while just one of many active safety technologies, has perhaps the best established track record to date. The majority of occupants in this study (53%) were involved in crashes where their vehicles had lost control. The effectiveness of ESC in preventing crashes varies widely from study to study but recent research, using British national data, suggest an effectiveness of 12% in crashes with seriously injured occupants, rising to 25% for fatal crashes alone (Thomas and Frampton, 2007). By comparison with this single active safety technology, the minimum potential benefit from improvements to belted occupant crashworthiness (where it could be established to a high degree of confidence) is 22% in this study, ranging upwards to a possible 32%. Therefore the case supporting further developments in passive safety still appears significant. This highlights the need to continue monitoring the performance of both crash and injury prevention technology so that the best strategies can be employed for casualty reduction.

Where further potential for crashworthiness was identified for belted occupants, the most common impact type was the frontal crash configuration (64%) followed by side crashes (30%). This result was unexpected, since frontal crash protection is considered to be at a more mature stage of development. UK crash injury data has shown that for newer car designs, side impacts have become almost as frequent as front impacts in crashes of all severities but most noticeably in serious injury crashes (Thomas and Frampton, 2003).

A number of functional requirements were identified to improve crashworthiness for belted occupants where passive protection potential existed. In Europe, occupant safety is designed around belted occupants. Ironically, reducing belt loads which cause AIS 3+ chest and abdominal injuries was the most frequently identified requirement, contributing 25% and 9% of the belted passive safety potential respectively. The predominant issue with belt loads to the chest concerned elderly occupants with reduced injury tolerance. This is an issue not picked up by crash tests but it is extremely important since a significantly larger number of seniors are expected to be using cars and involved in accidents in the next two decades and beyond (Morris et al. 2002). Addressing this issue does not necessarily have easy solutions, since introducing extra compliance in the belt system carries the risk of causing other injuries (through higher excursion) and may not be the optimal restraint for younger car occupants. Intelligent belt systems such as those proposed in the BOSCOS project (Hardy et al. 2005) have good potential but are complex. Rear seatbelt injuries were mainly to the abdomen of younger occupants who sustained no serious chest injuries. Those abdominal injuries were likely a consequence of abdominal compression due to the lap section of the seatbelt and attention to rear seatbelt geometry could be an important factor here. The safety performance of rear seating positions in frontal crashes is not assessed in European crash tests.

Reduction of crash loads to the femur and tibia in frontal crashes was the second most frequently identified functional requirement, accounting for 14% of the belted passive safety potential. Those injuries resembled the classic lower limb injuries found in 1980s vehicles but in this context they were not related to intrusion. Here they suggest the need for a more optimised restraint or attention to facia impact areas. EU regulation tests have assessed lower limb protection since 1996.

The third most common functional requirement concerned protection in side crashes. Providing ride-down for the head and chest in near-side crashes and reducing lateral excursion for far-side occupants each contributed 11% respectively to the requirements where potential existed for improved belted protection. In the case of near-side impacts there is a need to provide head and chest airbag restraints where none were fitted, in other words the adoption of current best practise. These are not mandated in EU regulations and it is possible to pass the side impact Directive without them. Interestingly, 5% of the functional requirements concerned optimising side airbag protection in cases where head and chest injuries occurred despite the presence of such protection. Far-side impacts are not assessed in Europe. Reducing occupant excursion into adjacent occupants and interior structures accounted for 11% of functional requirements. Much research has been carried out in this area in recent years (Fildes et al. 2007). The current study however highlights the opportunities for chest protection in far-side impacts. Serious head injury was a frequent occurrence with far-side impacts but mainly in cases where it was judged that there was limited potential for improvement, i.e. in cases where far-side intrusion had extended more than halfway across the vehicle.

At the outset of this work, the authors had expected to find a plethora of small issues where passive safety improvements might be beneficial based on the premise that the major issues have already been addressed. Instead the findings indicated five major functional requirements for improving belted occupant crashworthiness: a reduction of seatbelt loads on the chest and abdomen in frontal crashes, particularly for seniors; a reduction in femur and tibia loads in frontal crashes; provision of head and chest protection in near-side crashes; and reducing lateral excursion in far-side impacts. Together these functions accounted for 70% of the identified requirements. Other smaller requirements were identified, each contributing 5% or less to the total. These concerned compatibility in frontal impacts, neck loads in frontal impacts, occupant luggage separation, optimisation of existing side impact airbags, pelvis protection in side impacts, seatbelt loads on seniors in far-side crashes, control of spine movement in rear crashes and prevention of head ejection in rollovers.

A number of areas were encountered where further refinement of this study would be useful. Prevention of life-threatening injuries is, of course, a prime requirement but many impairing AIS 2 injuries to the lower and upper limb still occur. Therefore, a similar study focussing on AIS 2 injuries is recommended to identify additional areas of passive safety potential. Similarly, a detailed review of unbelted occupant crashes would be useful to identify the exact extent of belt use effectiveness in modern cars – this could be used to support a cost–benefit analysis of belt reminder systems. The relative benefits of active versus passive safety might be better quantified by comparing detailed crash causation data with crashworthiness data. That would require examination of databases that contain both types information. CCIS is not designed to collect detailed causation data. Ideally, for a study on crashworthiness potential, in-depth data would be available for every seriously injured occupant. While this is not feasible, CCIS specifically targets serious injuries in its sampling protocol and is designed to be representative of serious and fatal crashes in Great Britain. In that regard it is rare among European studies. By matching and weighting the results of this study to the GB national crash figures it would be possible to gain an idea of the actual numbers of British car occupants related to each area of passive safety potential.

Analysis of any aspect of real-world crash data carries with it a element of subjectivity. Defining crashes with passive protection potential is no exception. This study attempted to bring as much objectivity as possible to the process by employing a well-defined expert protocol which largely relied on survival space remaining in the vehicle and crashes which did not grossly exceed the impact severity of European crash tests.

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