THE POTENTIAL EFFECTIVENESS OF ADAPTIVE RESTRAINTS

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ABSTRACT

This study quantifies the effectiveness of current European car driver restraint systems in frontal crashes, notably steering wheel mounted airbags and seat belts (some pretensioned) compared to the previous generation of vehicles fitted with standard lap and diagonal seat belts alone. This data is then used to analyse and predict the potential effectiveness in terms of injury mitigation of future adaptive restraints for frontal impacts only. Adaptive restraint sytems were found to be likely to provide upto 41% and 25% reductions in MAIS 2+ and MAIS 3+ injury respectively, when compared with the previous generation of vehicles with seat belted drivers only. The study presents a method to predict the potential benefits of a change in vehicle restraint technology based on the UK's current injury car crash population. However, the project does not specify the technical criteria or details of such a future adaptive restraint system.

Keywords: Accident Investigations, Airbags, Frontal impacts, Injury Severity, Injury Probability.

THE EFFECTIVENESS OF CURRENT automotive occupant restraint systems in reducing injuries and fatalities in road traffic accidents is widely documented and recognised. In the UK, for example, since 1983 when seat belt use became mandatory for front seat car occupants, it is estimated that the number of fatalities have been reduced by approximately 25% (Rutherford et al, 1985). Similarly, the number of patients taken to hospital following a road accident have been reduced by 15% and this is believed to be accompanied by a 25% reduction in the number of patients requiring admission to wards. UK traffic surveys undertaken by the Transport Research Laboratory (TRL, LF2083) detail driver seat belt usage rates to range from 88% to 91% depending upon age and gender.

However, it is recognised that standard lap and diagonal seat belts have limitations. Mackay (1994a) identified five factors limiting the performance of current belt systems, arguably the most important being the risk of head injury from contact with steering wheels.

In the US many studies have reviewed airbag effectiveness and presented significant benefits, notably in the reductions of fatalities and serious injuries following frontal crashes (Crandall et al, 1994). The US has historically developed airbags to offer protection to both belted and unbelted front seat occupants. In some rare instances these airbag systems have caused serious or fatal injury, especially to small drivers and children (Kleinberger et al, 1997; Phen et al, 1998; Winston et al, 1996). Another study by Huelke et al, (1995) linked airbag deployments to a greater risk of forearm fractures. Subsequently, the new FMVSS 208 frontal crash protection criteria are designed to address the issues of airbag capacity and aggressiveness.

European airbags are typically designed to act as a 'Supplementary Restraint' to the seat belt system. As such these devices are generally less powerful and deploy at higher crash thresholds than those in the US. European studies have shown airbags to reduce MAIS 2+ injury to the cranium and face by 32% and 55% respectively (Frampton et al, 2000; Lenard et al, 1998). Very few European studies have highlighted potential limitations. Frampton et al (2000) noted an increase in the rate of clavicle fractures for airbag equipped cars compared to earlier models, but did not identify an increased risk of forearm fractures for these vehicles.

There are clearly many ways in which vehicle restraint systems could be improved to enhance the level of protection offered to occupants. It is suggested by Mackay et al (1994b) that, 'the next evolutionary stage in restraint design is to move away from a restraint system with fixed characteristics towards one which has variable characteristics'. The basic principal of these 'Intelligent' or 'Adaptive' restraints as they have become known is to afford the best possible protection to an individual based on their characteristics and those of the collision, thus further extending and increasing the levels of protection offered to car occupants. The ideal restraint device would be tailored to the following variables:

- The type and severity of the specific crash pulse.
- The specifics of the compartment geometry and crush properties of the car.
- The characteristics of the occupant in terms of gender, age, stature and weight.
- Individual tolerance to injury and predisposed medical conditions.
- The specific sitting position of the occupant.

The use of adaptive restraints in vehicles potentially allows these variables to be assessed, so the appropriate restraint characteristics can be applied. The adaptive system could differentiate based on the nature and severity of the impact, for example, whether it is a high or low speed crash and possibly detect the early onset of compartment intrusion.

Occupant characteristics could be incorporated into the restraint system perhaps through the use of a 'smart card' system (Mackay et al, 1994b), similar to the system used in certain current vehicles to make automatic seat adjustments. The card would contain the necessary anthropometric details, such as gender, age, stature and weight of the occupant. Alternatively active monitoring of an occupant's position and their mass from seat sensors could be used to describe their basic characteristics. This information could actively adjust or 'tune' the performance criteria of the seat belt and airbag for any given occupant and crash. For example, the rate and amount of seat belt pretensioning and the timing and relative stiffness of the airbag could be optimised for any given crash and associated occupant characteristics.

Adaptive restraints clearly have a significant theoretical potential for improving the level of protection offered to vehicle occupants. New technologies are reaching an advanced state of development and it is, therefore, timely that this project attempts a quantitative estimate of potential injury reductions that could result from the use of adaptive restraints.

METHODOLOGY

The paper is divided into two distinct areas, firstly a brief review of current European airbag effectiveness in frontal crashes and then based on these findings and other work, a predictive study to estimate the potential effectiveness of future adaptive restraints. In-depth crash data from the UK's Co-operative Crash Injury Study (CCIS) was analysed (Mackay et al, 1985; Hassan et al, 1995).

The CCIS is an ongoing project, which has collected real world crash data since 1983. Vehicle examinations are undertaken at recovery garages several days after the collision. Car occupant injury information is collected from hospital records, coroners' reports and questionnaires sent to survivors. The casualties' injuries are coded using the Abbreviated Injury Scale (AIS, AAAM 1990 Revision). Accidents are investigated according to a stratified sampling procedure, which favours cars containing fatal or seriously injured occupants as defined by the British Government definitions of fatal, serious and slight.

The crash severity parameter used is the Equivalent Test Speed (ETS). This is calculated on the assumption that the car's deformation or crush was caused by an impact with an immovable rigid object. The ETS is not the car's change of velocity (delta-v) for most crashes, but it is a reasonable estimate.

When comparisons are made of different variables and statistically tested, the test level used is $p \leq 0.05$ for acceptance or rejection of any significance.

CCIS data was available for the calendar years 1992 to 2000 and comprised a wide variety of different European cars. The selection criteria for the cases to be included were:

- One impact only.
- Right-hand drive standard British cars only.
- Standard Lap and Diagonal seat belted drivers only (some had airbags - activated and not).
- Frontal impact only, with a Principal Direction of Force $\pm$ 60° head-on (10,11,12,1 and 2 o'clock).
- Known injury outcome (MAIS).
- Vehicles manufactured between calendar years 1989 and 2000 only.

Adaptive Restraints - The sample of cases were divided into different crash and occupant types. The crashes were grouped based on the nature and extent of the car damage including the intrusion characteristics of the interior structure and steering wheel and if known the specific ETS. The crashes were grouped as:

- **All Low Energy** (309 Crashes, 13.2%)
  (ETS $\leq$ 15km/h) or where ETS was not known coincident with no airbag deployment, from Collision Deformation Classification (CDC) -Damage height 'E' or 'M' or 'H' and Extent = 1.
- **Moderate Energy, Low Intrusion** (1602 Crashes, 68.6%)
  (ETS 16 to 64km/h and intrusion $\leq$ 9cm) or where ETS was not known, from CDC - Damage height 'A' or 'E' or 'L' and Pattern 'W' or 'N' or 'E' and 2 ≤ Extent ≤ 4.
- **Moderate Energy, High Intrusion** (314 Crashes, 13.4%)
  (ETS 16 to 64km/h and intrusion $\geq$ 10cm) or where ETS was not known, from CDC - Damage height 'A' or 'E' or 'L' and Pattern 'W' or 'N' or 'E' and 2 ≤ Extent ≤ 4.
- **High Energy, Low Intrusion** (32 Crashes, 1.4%)
  (ETS 65 to 109km/h and intrusion $\leq$ 9cm) or where ETS was not known, from CDC - Damage height 'A' or 'E' and Pattern 'W' or 'N' or 'E' and Extent ≥ 5.
- **High Energy, High Intrusion** (78 Crashes, 3.3%)
  (ETS 65 to 109km/h and intrusion $\geq$ 10cm) or where ETS was not known, from CDC - Damage height 'A' or 'E' and Pattern 'W' or 'N' or 'E' and Extent ≥ 5.

All drivers in the sample were grouped based on their gender, age, height and weight. It is widely accepted that both gender and age have a significant effect on an individuals biomechanical tolerance or resistance to injury (Mackay 1994b; Evans; Viano 1989). Research by Zhou et al (1996) suggested that with respect to thoracic injury tolerance, occupants could be divided into three groups up to 35, 36-65 and 66 years and over. These age groups have been adopted for this paper.

The stature or height is the only available indicator in the CCIS data of the likely distance between the steering wheel and the driver. Consequently, although it is recognised that the relationship between stature and sitting height is complex, it is assumed for the purposes of this study that taller people sit at a greater distance from the steering wheel than those of shorter stature. It is believed that an appropriate restraint response is a function of an occupant's proximity to the forward structures. Similarly, a driver's weight will have an important effect during the crash phase on their energy, momentum and trajectory. Hill et al (1992), for example, found that weight had a statistically significant effect on chest injury severity.

For the purpose of this predictive exercise it was decided to group the drivers as detailed below.

- **Shorter drivers** $\leq$ 25th percentile female ($\leq$ 1.57 metres) (216 Drivers, 9.3%)
- **Heavier drivers** $\geq$ 75th percentile male ($\geq$ 88 kilograms) (225 Drivers, 9.6%)
- **Older drivers** $\geq$ 66 years old (148 Drivers, 6.3%)
- **All other drivers** (1746 Drivers, 74.8%)

All shorter drivers were grouped regardless of weight or age, then heavier drivers of any age, then older. The groups were selected based on what the authors believed would be examples of drivers who may benefit from different restraint characteristics if they experienced similar crashes.

Injury Reduction – In the final stage of the analysis 'Injury Severity Reduction Matrices' (Tables 7, 8 and 9) were produced for each driver group, covering all the relevant collision types. A logical progression through the likely potential effect of a new restraint system was undertaken to estimate if an injury reduction would take place for a certain group of drivers, given their collision severity, type of injury and associated contacts. For example, Table 8 details that an 'Older driver' would optimistically (estimate 2) have had any thoracic injury reduced by up to 2 AIS points for 'All Low Energy' crashes if an adaptive restraint system was present.

Both pessimistic and optimistic (estimates 1 and 2) potential reductions in the severity an AIS injury to any given body region were assigned. These estimates by their nature can be described as subjective, but by being both pessimistic and optimistic a range is presented. Possible injuries induced by the restraint systems are not considered.

RESULTS

Table 1 shows the distribution of MAIS for 2,335 belted drivers by airbag deployment. There are different sorts of airbag systems in the study. Approximately 30% of the drivers sustained MAIS 2+ injury and 28% of the cars had a deployed or activated steering wheel mounted airbag. There is no difference in the respective MAIS rates for cars with or without deployed airbags. However, such comparisons of crashes need to be made carefully allowing for potential differences in the two groups of drivers and their respective impacts.

This analysis qualifies potentially many vehicle changes, not just the effectiveness of airbags. Introductions of other restraint systems and changes to vehicle structures have all occurred in the period. For example, 551 of the vehicles had activated seat belt pretensioners, 23% of which were fitted to cars where an airbag didn't deploy or wasn't fitted. Analysis of cars with and without seat belt pretensioners was inconclusive with no differences being observed in the data. The direction of the impacts, the nature of the damage, objects struck and crash severity (ETS) are all described in Tables 2 – 5.

Table 1: MAIS Distributions by Airbag Status

MAIS	No Airbag Fitted or Airbag Not Deployed		Airbag Deployed		All	
0	226	(13.39%)	66	(10.20%)	292	(12.51%)
1	956	(56.64%)	392	(60.59%)	1348	(57.73%)
2	321	(19.02%)	118	(18.24%)	439	(18.80%)
3	104	(6.16%)	46	(7.11%)	150	(6.42%)
4	38	(2.25%)	16	(2.47%)	54	(2.31%)
5	23	(1.36%)	6	(0.93%)	29	(1.24%)
6	20	(1.18%)	3	(0.46%)	23	(0.99%)
Total	1688		647		2335	

Table 2: MAIS Distributions by Principal Direction of Force and Airbag Status

	CDC Principal Direction of Force – O'clock				
	10 (-60°)	11 (-30°)	12 (0°)	1 (+30°)	2 (+60°)
No Airbag Fitted or Airbag Not Deployed					
MAIS 0 - 6 (N=1688)	2.31%	11.91%	71.27%	13.15%	1.36%
MAIS ≤ 1 (n=1182)	2.79%	12.01%	71.15%	12.52%	1.52%
MAIS 2+ (n=506)	1.19%	11.66%	71.54%	14.62%	0.99%
Airbag Deployed					
MAIS 0 - 6 (N=647)	1.39%	10.66%	74.96%	12.36%	0.62%
MAIS ≤ 1 (n=458)	1.53%	11.35%	74.67%	11.79%	0.66%
MAIS 2+ (n=189)	1.06%	8.99%	75.66%	13.76%	0.53%

Figure 1: Distribution of all Vehicle Direct Impact Damage (from CDC)

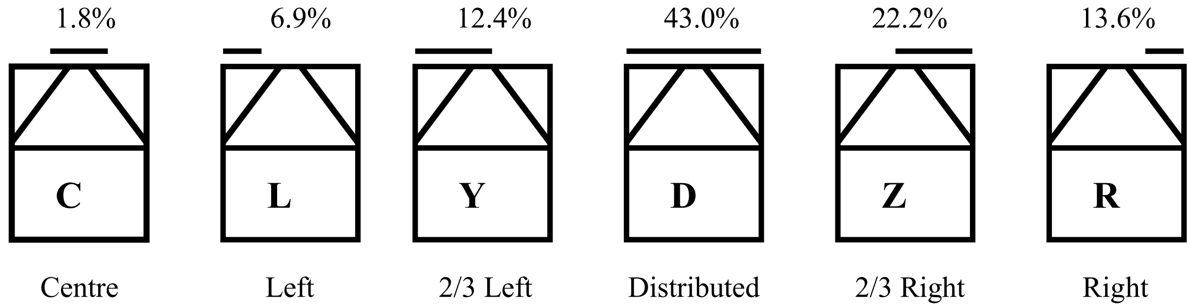

Table 3: Distribution of Vehicle Direct Impact Damage (from CDC) by Airbag Status and MAIS

	C (42)	L (162)	Y (290)	D (1004)	Z (519)	R (318)
No Airbag Fitted or Airbag Not Deployed						
MAIS 0 - 6 (N=1688)	1.95%	7.94%	13.21%	41.53%	21.74%	13.63%
MAIS ≤ 1 (n=1182)	2.12%	10.24%	14.21%	38.41%	20.05%	14.97%
MAIS ≥ 2 (n=506)	1.58%	2.57%	10.87%	48.81%	25.69%	10.47%
Airbag Deployed						
MAIS 0 - 6 (N=647)	1.39%	4.33%	10.36%	46.83%	23.49%	13.60%
MAIS ≤ 1 (n=458)	1.31%	5.46%	11.57%	42.36%	24.45%	14.85%
MAIS ≥ 2 (n=189)	1.59%	1.59%	7.41%	57.67%	21.16%	10.58%

Table 4: Distribution of Object Struck by Airbag Status and MAIS

	Car (1601)	LGV* (168)	HGV** (283)	Narrow (89)	Wide (139)	Other (55)
No Airbag Fitted or Airbag Not Deployed						
MAIS 0 - 6 (N=1688)	68.25%	7.29%	12.20%	3.73%	5.75%	2.78%
MAIS ≤ 1 (n=1182)	70.39%	6.85%	9.48%	4.57%	5.58%	3.13%
MAIS ≥ 2 (n=506)	63.24%	8.30%	18.58%	1.78%	6.13%	1.98%
Airbag Deployed						
MAIS 0 - 6 (N=647)	69.40%	6.96%	11.90%	4.02%	6.49%	1.24%
MAIS ≤ 1 (n=458)	72.49%	6.11%	8.73%	4.37%	6.77%	1.53%
MAIS ≥ 2 (n=189)	61.90%	8.99%	19.58%	3.17%	5.82%	0.53%

(* LGV – Light Goods Vehicle; ** HGV – Heavy Goods Vehicle, or Bus or Coach)

Table 5: Crash Severity (ETS) by MAIS by Airbag Status

	No Airbag Fitted or Airbag Not Deployed			Airbag Deployed		
	Median ETS km/h	25th to 75th Percentile of ETS (km/h)	N	Median ETS km/h	25th to 75th Percentile of ETS (km/h)	N
MAIS 0-6	28	22-37	1218	29	22-39	495
MAIS 1+	29	23-39	1069	30	22-40	453
MAIS 2+	38	29-51	376	39	30-52	154
MAIS 3+	49	37-65	125	51	39-60	58

Males accounted for 63% of the sample and were a significantly ($p=0.02$) higher proportion (67%) of the drivers with deployed airbags. The ages of drivers with and without deployed airbags were very similar, having median ages of 38 and 37 years respectively (min 16, max 90). The cars with deployed airbags in the sample were significantly newer than without, median years of manufacture of 1996 and 1992 respectively (min 1989, max 2000).

The distributions of objects hit and crash severity (ETS) were comparable. With the possible exception that drivers with deployed airbags experienced proportionally more MAIS 2+ crashes with 'Narrow' objects. Crashes with poles and trees are known to be a challenge for airbag systems. The Principal Direction of Force (or impact angle) and the pattern of damage or amount of direct loading to the vehicles varied between the two groups. The MAIS 2+ airbag deployed drivers experienced a greater percentage of both 'Distributed' damage (more than two thirds) to the front structure and impacts from 12 o'clock (or head-on). The vast majority of all the impacts were from $\pm$ 30° with other cars. Crashes with HGVs accounted for approximately 20% of MAIS 2+ casualties.

No statistical differences were observed between the driver airbag status and MAIS, as shown in Table 6. However, the reduction in cranium and facial injuries at both AIS 2+ and AIS 3+ was significant ($p<0.05$). There was a significant increase ($p<0.05$) in the rate of right shoulder injury at AIS 2+ in the airbag-deployed cases due to seat belt webbing contact. Also, the rate of arm fractures (upper and lower) was significantly greater ($p=0.05$) in the airbag-deployed cases, contact or causation codes were rarely assigned to these injuries. No other differences in injury rates were observed.

Table 6: MAIS 2+ Driver Body Regions Injured by Airbag Status

	No Airbag Fitted or Airbag Not Deployed (N = 506)				**Driver Airbag Deployed (N=189)**			
	AIS 0	**AIS 1**	**AIS 2**	**AIS 3+**	**AIS 0**	**AIS 1**	**AIS 2**	**AIS 3+**
MAIS All Body Regions	**-**	**-**	**63%** (321)	**37%** (185)	**-**	**-**	**62%** (118)	**38%** (71)
HEAD	**35%**	**29%**	**21%**	**15%**	**57%**	**23%**	**12%**	**8%**
Cranium	64%	4%	17%	14%	75%	7%	10%	8%
Face	42%	48%	9%	1%	66%	31%	2%	1%
NECK	**76%**	**19%**	**3%**	**3%**	**82%**	**16%**	**1%**	**1%**
UPPER EXTREMITY	**40%**	**30%**	**25%**	**6%**	**34%**	**26%**	**31%**	**10%**
Right Shoulder	79%	10%	11%	-	70%	14%	16%	-
Arms	52%	28%	15%	6%	48%	26%	17%	10%
THORAX	**28%**	**29%**	**27%**	**16%**	**31%**	**26%**	**25%**	**19%**
ABDOMEN	**68%**	**23%**	**7%**	**3%**	**58%**	**30%**	**9%**	**3%**
LOWER EXTREMITY	**28%**	**32%**	**23%**	**18%**	**22%**	**28%**	**28%**	**22%**
Pelvis	90%	-	6%	4%	91%	1%	6%	2%
Right Femur/knee	56%	27%	6%	11%	55%	25%	5%	15%
Left Femur/knee	62%	26%	7%	5%	59%	31%	4%	6%
Right leg	64%	18%	15%	3%	60%	17%	20%	3%
Left leg	72%	19%	8%	1%	66%	19%	14%	2%

<u>The Effectiveness of Adaptive Restraints</u> – 'Injury Severity Reduction Matrices' were applied to the CCIS data sample. Tables 7, 8 and 9 detail the predicted effects of an adaptive restraint system for the different groups of crashes and drivers, per body region. European airbags have been observed in this study and others to only significantly reduce the rate of head (cranium and facial) injuries, therefore drivers who had a deployed airbag are assigned less head injury reduction than those without. All other body regions are treated equally, regardless of airbag status.

The driver and crash groups can be re-defined and similarly the appropriate reductions in AIS can be amended. The method of analysis is therefore flexible to the properties of the proposed or predicted adaptive restraint system. This study has not attempted to define the exact characteristics of the restraint system. However, it has assumed a theoretical potential reduction in seat belt loads, head contacts and injury caused by knee contacts due to excessive forward excursion at low or moderate energy impacts with low intrusion.

Figure 7 – Injury Severity Reduction Matrix for Head Injuries

Crash Severity/ Intrusion	Head or Face AIS Reductions							
	Shorter drivers ≤ 25th %ile female		Heavier drivers ≥ 75th %ile Male		Older drivers ≥ 66 years		All other drivers	
Estimates Pessimistic = 1 Optimistic = 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2
All Low Energy	**-2 (-1)**	**-3 (-2)**	**-2 (-1)**	**-3 (-2)**	**-2 (-1)**	**-3 (-2)**	**-2 (-1)**	**-3 (-2)**
Moderate Energy, Low Intrusion	**-2 (-1)**	**-3 (-2)**	**-2 (-1)**	**-3 (-2)**	**-2 (-1)**	**-3 (-2)**	**-2 (-1)**	**-3 (-2)**
Moderate Energy, High Intrusion	**0 (0)**	**-1 (0)**	**0 (0)**	**-1 (0)**	**0 (0)**	**-1 (0)**	**0 (0)**	**-1 (0)**
High Energy and Low Intrusion	**-1 (0)**	**-1 (0)**	**-1 (0)**	**-1 (0)**	**-1 (0)**	**-1 (0)**	**-1 (0)**	**-2 (-1)**
High Energy and High intrusion	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**

Note: Values in parenthesis are for vehicles in sample with a deployed-airbag

Figure 8 – Injury Severity Reduction Matrix for Thorax, Abdomen and Right Shoulder Injuries

Crash Severity/ Intrusion	Thoracic or Abdominal or Right Shoulder AIS Reductions							
	Shorter drivers ≤ 25th %ile female		Heavier drivers ≥ 75th %ile Male		Older drivers ≥ 66 years		All other drivers	
Estimates Pessimistic = 1 Optimistic = 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2
All Low Energy	**-1**	**-2**	**-1**	**-3**	**-1**	**-2**	**-1**	**-3**
Moderate Energy, Low Intrusion	**-1**	**-1**	**-1**	**-3**	**-1**	**-2**	**-1**	**-3**
Moderate Energy, High Intrusion	**0**	**0**	**0**	**-1**	**0**	**-1**	**0**	**-1**
High Energy and Low Intrusion	**0**	**0**	**0**	**-1**	**0**	**0**	**-1**	**-2**
High Energy and High intrusion	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Figure 9 – Injury Severity Reduction Matrix for Lower Limbs

Crash Severity/ Intrusion	Lower limb AIS Reductions attributed to knee contacts (Pelvis, Thighs and Knees only)							
	Shorter drivers ≤ 25th %ile female		Heavier drivers ≥ 75th %ile Male		Older drivers ≥ 66 years		All other drivers	
Estimates Pessimistic = 1 Optimistic = 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2	Estimate 1	Estimate 2
All Low Energy	**-1**	**-2**	**-1**	**-3**	**-1**	**-2**	**-2**	**-3**
Moderate Energy, Low Intrusion	**0**	**-1**	**0**	**-3**	**0**	**-2**	**-2**	**-3**
Moderate Energy, High Intrusion	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
High Energy and Low Intrusion	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-1**
High Energy and High intrusion	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

The number of drivers with MAIS 2+ and MAIS 3+ injury in the CCIS sample were 695 and 256 respectively. Following the injury reductions calculated by the adaptive restraint matrices, these figures were significantly reduced as shown in Table 10. The effectiveness of the adaptive restraints is calculated using the following equation:

$$Effectiveness = \frac{n_0 - n_1}{n_0} \times 100\%$$

Where n_0 is the frequency of injury above or equal to the AIS level of interest, before injury reduction, whilst n_1 is the frequency afterwards.

Table 10: Potential Effectiveness of Adaptive Restraints

	Potential Effectiveness					
	MAIS 2+			MAIS 3+		
	n_o	Pessimistic % n_1=( )	Optimistic % n_1=( )	n_o	Pessimistic % n_1=( )	Optimistic % n_1=( )
Whole Body (Over all regions) **MAIS**	695	33% (463)	41% (410)	256	14% (221)	25% (193)
HEAD	221	29% (157)	50% (110)	93	9% (85)	25% (70)
NECK	33	0% (33)*	0% (33)*	15	0% (15)*	0% (15)*
UPPER EXTREMITIES	228	21% (181)	28% (165)	46	0% (46)	0% (46)
Right Shoulder	84	60% (34)	86% (12)	-	-	-
Arms*	153	0 (153)*	0 (153)*	46	0% (46)*	0% (46)*
THORAX	299	53% (142)	65% (106)	117	15% (100)	35% (76)
ABDOMEN	71	17% (59)	45% (39)	20	5% (19)	20% (16)
LOWER EXTREMITIES	300	11% (268)	14% (257)	133	8% (123)	14% (114)
Pelvis	66	8% (61)	14% (57)	25	4% (24)	12% (22)
Right Femur/knee	122	16% (103)	20% (98)	83	6% (78)	15% (71)
Left Femur/knee	80	20% (64)	36% (51)	35	14% (30)	23% (27)
Right leg*	134	0% (134)*	0% (134)*	21	0% (21)*	0% (21)*
Left leg*	79	0% (79)*	0% (79)*	11	0% (11)*	0% (11)*

(* No injury reduction was predicted for these body regions)

DISCUSSION

Current Airbags - This study presents the largest data set to date of European steering wheel mounted deployed airbags for belted drivers who experienced just one frontal impact.

European airbag deployments following frontal crashes were not found to alter the overall maximum level of AIS injury, (MAIS), for belted drivers. No difference in the driver MAIS was noted for crashes with and without deployed airbags for equivalent frontal crashes with similar characteristics. However, significant reductions in AIS 2+ injury of 42% and 70% for cranium and facial injuries respectively were noted for the airbag-deployed cases. Frampton et al (2000) and Lenard et al (1998) both suggested that airbags might be less effective at reducing the incidence of brain injuries compared to skull fractures. The rates of head bony and brain injury were found to be dissimilar between the cases with airbag deployment and those without, but no statistical association was found to support the hypothesis that the incidence of brain injury is not reduced by airbags. The crashes where serious head injury was noted, especially for airbag-deployed cases were typically severe and often associated with compartment and/or steering wheel intrusion.

Drivers with deployed airbags had increased rates of upper extremity injuries which were attributed to seat belt loads applied to the right shoulder and arm fractures (humerus, ulna and radius) or dislocations that may have been a result of contact with a deploying airbag. It is difficult to establish the injury mechanism or associated contact source for such lower arm injuries. Airbags did not effect the rate of belted driver chest or abdominal injury. The majority of the airbag systems investigated were European style ‘Supplementary Restraints’; these are generally smaller and deploy at a higher threshold than the standard US systems.

The differences between the two groups, those with deployed airbags and without must be borne in mind. The newer vehicles with a higher proportion of deployed airbags were more likely to have a male driver. The airbag-deployed cases were found to experience proportionally more crashes with greater direct contact damage to the front structure (greater distributed loading). The drivers with deployed airbags had a lower percentage of oblique impacts, where the head contact with the airbag may not be as efficient at reducing injury as the head-on angle. All other factors between the groups were found to be comparable.

Adaptive Restraints - The results predict that the overall effectiveness of adaptive restraint systems, in terms of mitigation of injuries rated at MAIS 3+, is likely to be between 14% and 25%. The results describe additional benefits that could be achieved based on a predicted restraint system which utilises adaptive airbags and seat belts for drivers who were originally injured while equipped with standard lap and diagonal seat belts alone, some without and some with steering wheel mounted airbags. The analysis of current European airbag effectiveness helped to define the body regions, which ideally require further protection from a more advanced or an adaptive restraint system. Given the different driver and crash types, potential injury reduction matrices were defined.

The study has successfully designed and constructed a new analysis system. The predictive system has been demonstrated to be a useful tool to investigate how injury patterns might be modified according to alternative schemes for injury mitigation, based on a range of crashes, casualty and injury factors. A major strength of the system is that the results are expressed in terms of MAIS or AIS for individual body regions and, therefore, show how changes to specific types of injury will affect the overall pattern of multiple injuries.

By mapping out a number of schemes for injury mitigation, considering various potential restraint possibilities and after careful consideration of the available literature, ideas were developed based upon the judgements of experienced researchers and engineers. It must, therefore, be emphasised that any one scheme will be inherently subjective in nature. There can be no single correct scheme or result. The intention of this study was to calculate a range of results, based on a range of possibilities for a future theoretical adaptive restraint system.

The ‘Injury Severity Reduction Matrices’ (Tables 7, 8 and 9) can be designed to describe the likely advantages or disadvantages of any proposed future restraint change for a wide variety of different crash and car occupant groups, and thus be used to predict any benefits based on real-world injury data. This study presents a limited grouping of crash and driver characteristics, but larger matrices could be used to evaluate other potential design changes where the analyses may be more case sensitive. Similarly, the actual AIS reductions defined in this study can be altered for specific restraint systems or to reflect new data that better describes the potential effectiveness of variable restraint technology.

An important point to note is that the ‘Injury Severity Reduction Matrices’ assume different potential reductions in injury or AIS severity for different crash types, driver characteristics and body region injured. Therefore, even the performance of the theoretical adaptive restraint system presented in this study has its limitations. These limitations account for the different rates of injury reduction at the AIS 2+ and AIS 3+ levels.

Ideally, future work would also build on the expanding state of biomechanical knowledge and include inputs from other experienced researchers and engineers. The analysis presented is possibly limited by the technical feasibility of the proposed adaptive restraint system. In addition the quantification of any benefits is restricted by the scope of the work to date, with only frontal impacts considered. Additional work might address other impact types. The population of drivers and their characteristics is known to be changing within Europe. For example, more females and elderly people are driving cars (Cuerden et al, 1998). Thus, as the population changes, the associated benefits of any one given system are also likely to alter.

CCIS data is naturally biased towards serious and fatal accidents. Therefore results cannot be generalised easily over the whole population. For instance, we can suggest using this analytical technique that between 9% and 25% of people who had a serious (AIS 3+) head injury before won't have that injury if an adaptive restraint is implemented. What we cannot say though is that head injuries throughout the population will generally be reduced by that amount, because in the population as a whole the median crash severity will be lower so there is less opportunity for injury reduction.

The project only addresses positive effects that adaptive restraint technology can provide. No account is taken of injuries that can result from the presence of the restraint system, except that reduced benefits are estimated for shorter drivers and this may be taken to imply airbag system limitations under some conditions. The analysis system is flexible enough to be able to increase the value of injury severity scores, as well as reducing them. This facility might be utilised at some other stage, so that injuries caused by seat belt crash loads or extreme proximity to a deploying airbag might also be included.

A further limitation to the analysis carried out in this study was the use of driver stature as an indicator of sitting position. It is recognised that the relationship between these two variables is complex since two identical drivers might choose to sit in very different positions, and conversely, two very different drivers may take the same position. Vehicle size, as well as differences in the preferences of drivers, all contributes to the sitting position taken which cannot, therefore, be fully predicted by stature. Given that no other indicator was available, and given the importance of considering the distance between the driver and the steering wheel, the use of stature, selected at the less than the UK 25th percentile female height (1.57m) is felt to be justified in this analysis.

The use of adaptive restraint systems in future passenger vehicles is clearly supported by the results in this study. It is important to note, however, that the results are limited in their applicability by both the technical and statistical considerations outlined above.

This analysis has categorised driver and crash characteristics to represent and include the wide range of variability found in the real-world population. In essence, the future of restraint systems lies in the development of increasingly variable restraint components which can be combined within an adaptive system to provide improved protection for a greater number of vehicle occupants.

CONCLUSIONS

For frontal impacts seat belted drivers, with current European deployed airbags were compared to those without and found to:

- Experience no differences in MAIS 2+ injuries for similar crashes.
- Experience a 42% reduction in AIS 2+ cranium injuries.
- Experience a 70% reduction in AIS 2+ facial injuries.
- Experience no differences in AIS 2+ chest injuries.
- Experience significantly more AIS 2+ injuries to their arms and right shoulder. (The shoulder injuries were attributed to seat belt loads)

Adaptive Restraints for belted drivers in frontal crashes are predicted to:

- Reduce MAIS 2+ injuries by between 33% and 41%, over current, European vehicle restraint systems
- Reduce MAIS 3+ injuries by between 14% and 25%, over current, European vehicle restraint systems.

The use of adaptive restraint systems in future vehicles is supported by this study. Current results are limited to some extent by certain technical and statistical considerations. These may be overcome by future work.

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Further information on CCIS can be found at http://www.ukccis.com/

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