Comparison of Rollover Crash characteristicsof Passenger Cars and Sport Utility Vehicles

Yuanzhi Hu, A.M. Hassan, Rong Guo, Clive N. Sturgess

Birmingham Automotive Safety Centre
School of Engineering
Mechanical Engineering
The University of Birmingham
Edgbaston , Birmingham B15 2TT UK

Abstract – Study focused on pure rollover crashes (a single vehicle rolls with ground impact only) comparison between passenger cars and Sport Utility Vehicles (SUVs) in UK. The data was obtained from the Co-operative Crash Injury Study (CCIS) database in UK, calendar years 1998 to 2002.The study compared the characteristics of pure rollovers between passenger cars and SUVs including the injuries of front seat occupants, restrained condition, injury distribution, injury causation and Roof Intrusion. The results indicated that rollover crash is a serious event for SUVs, as front and side impacts are serious events for passenger cars; belt usage may have significant benefits to decrease ejection and serious injuries in pure rollovers; external objects were the highest frequency of injury contact for front seat occupants both in passenger cars and SUVs; roof intrusion for SUV is not an obvious factor for serious injury as it does for cars.

Key words: Rollover crashes, Sport Utility Vehicle, Passenger car

1 Introduction

Rollover crashes can be the most violent in terms of occupant injury outcome. Vehicles have different characteristics of rollover. Passenger cars have a lower occurrence in rollover, but the rollovers of passenger cars, the dominating fleet, are still a big threat to life. Although rollover accidents cover only approximately 9 % of all vehicle accidents in Europe, more than 25 % of all seriously injured occupants were involved in an accident where the car rolled [1]. Passenger cars represent saloon, hatchback and estate. Convertible and car derivative are excluded. Sport utility vehicle (SUV), for its higher rollover occurrence, also continues to be a growing safety problem as the proportion of SUVs in the vehicle fleet is increasing.

The analysis of rollovers between passenger cars and SUVs is expected to offer a comprehensive understanding of rollover.

The results indicate that rollover crash is a serious event for SUVs, as front and side impacts are serious events for passenger cars, and belt usage may have some benefits to decrease ejection and serious injuries in pure rollovers. It also examined accident data to describe how belt usage relates to injury outcomes and ejections.

2 Data Source

The Data for this study comes from the in-depth Co-operative Crash Injury Study (CCIS) database in UK for the years 1998-2002. The CCIS is an on-going crash injury research project in UK [8]. It follows an established protocol to select vehicle crashes for examination and inclusion in the database [9]. All accidents satisfied some certain criteria are studies. It also allows on average, about 50% of the fatal and serious injury cases and a further 15% of slight injury cases and 10% damage only cases [2]. A total of over 1300 vehicles are investigated each year. The sample represents all levels of injury while being biased towards the more serious and fatal cases.

In this study, the total of passenger cars is 4,971, and occupants in passenger cars are 31,881. 153 SUVs and 947 corresponding occupants are included. The totals of passenger cars and SUVs which experienced single-event rollover without impact objects are 212 and 28, respectively. The data summary is shown in Table 1.

Table 1 Data Summary

	No.	Occupants	No. of Pure rollovers	Occupants in pure rollovers
Passenger Cars	4971	31881	212	958
SUVs	153	947	28	132

To compare the results between different categories, the following terms were defined for the study.

Pure Rollover- a single vehicle rolls without impact objects.

Rollover with impact - A rollover that occurred before impact, between impacts or after impact is classified as rollover with impact. In such rollovers, it's difficult to get the exact injuries that only came from rollover not from impact.

Roll direction - It was classified as Off Side, Near Side, Rear over Front and Front over Rear. Roll to off side occurs when a roll happens to the opposite curb of driving way in driving. It's a roll with the driver side leading; Roll to near side represents a roll to the curb of driving way in driving. It's a roll with the front passenger side leading.

Ejection - Ejection is divided into complete and partial. Complete ejection occurs when the whole body of an occupant egresses to the outside of the vehicle and remains outside of that vehicle following completion of the collision event. Partial ejection occurs when some part of the occupant's body egresses through a portal of the vehicle body and contacts an external object [2].

Injuries and Injury Severity - The occupant injuries are recorded using the Abbreviated Injury Scale (AIS) system. Maximum Abbreviated Injury Score (MAIS) refers to the highest AIS sustained by an occupant [3]. The injury severity is grouped two by MAIS: no injury (MAIS = 0) or slight injury (MAIS is 1-2) and serious to fatal injury (MAIS is 3~6).

Front Seat Occupant (FSO) - FSO is the occupant who sit in the front seat of vehicle, including driver.

3 Result

3.1 Comparison of Rollover

Figure 1, 2 Show the distribution of passenger cars and SUVs according to the crash modes. Front impact was the highest frequent crash type for both of them as they accounted for 58%, 50% respectively. Side impact ranked the second highest frequency and pure rollover was the lowest frequency crash type for passenger cars, while SUVs' pure rollover ranked the third (18%) highest frequent crash types, followed by side and rear impacts. It shows that passenger cars were not inclined to rollover as SUVs did.

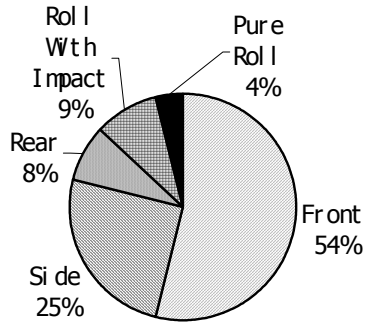


Fig. 1 Impact Type Distribution for passenger Cars

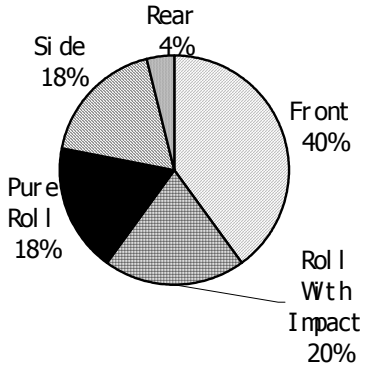


Fig. 2 Impact Type Distribution for SUVs

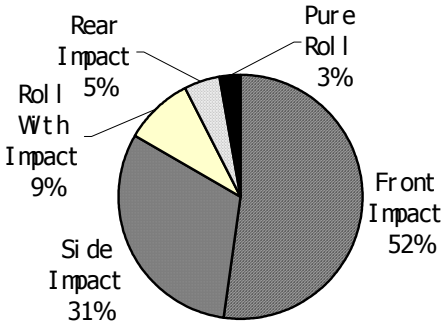


Fig. 3 Distribution of Occupants Injuries (MAIS 3+) for crash type in Passenger Car

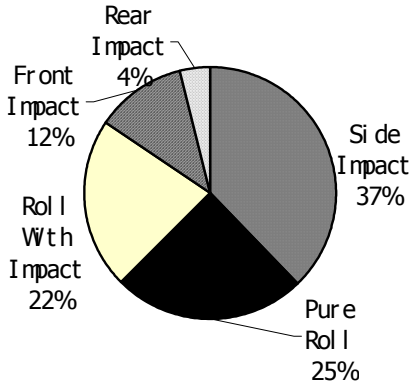


Fig. 4 Distribution of Occupants Injuries (MAIS 3+) for crash type in SUV

Considering the serious to fatal injuries (MAIS≥3) corresponding to the crash types for two kinds of vehicle, there is some obvious difference as figure 3, 4 shown. The proportions of injuries by crash types for passenger cars had the similar order as those of crash types. For SUVs, The percentages of crash modes did not reflect the injury risk that an occupant is likely to experience, for the proportions of injuries in pure rollover is the second highest frequency as it accounted for 25%. It indicated that rollover crash is a severe event.

Roll Direction - The distribution of roll direction in pure rollovers between passenger cars and SUVs is shown in Table 2. It's obvious that rolls to off side and near side were the majority. Less than 8% pure rollovers of passenger cars and SUVs rolled from rear over front or from front over rear. For passenger cars, roll to off side and near side has the similar proportion while SUVs are inclined to roll to off side.

Roll Numbers - The proportions of roll numbers were similar for both of them as shown in Table 3. Over 50% passenger cars and SUVs were liable to 1/4~1/2 turn.

Table 2 Distribution of roll direction in pure rollover

	Passenger cars		*SUVs*	
Roll Direction	*No.*	*%*	*No.*	*%*
Off side	98	46.2	17	60.7
Near Side	90	42.5	9	32.1
Rear over front	8	3.8	1	3.6
Front over rear	1	0.5	1	3.6
N/A	15	7.0	0	0
Total	212	100	28	100

Table 3 Distribution of roll numbers in pure rollover

	Passenger cars		*SUVs*	
Turns	*No.*	*%*	*No.*	*%*
1/4~1/2	108	50.9	14	50.0
3/4~1	44	20.8	9	32.1
>1	60	28.3	5	17.9
Total	212	100	28	100

3.2 occupant Injury

Injuries in pure rollover are the important comparing aspect between passenger cars and SUVs. The analysis of occupants and their injuries was restricted to those in the front seat.

Table 4 Comparison of injury severity for FSO in pure rollover

Injury Severity (MAIS)	*FSO of cars in pure Rollover*				*FSO of SUVs in pure Rollover*			
	Belted		*unbelted*		*Belted*		*unbelted*	
0-2	513	73.9%	51	42.1%	61	87.1%	1	5.9%
3-6	181	26.1%	70	57.9%	9	12.9%	16	94.1%
Total	694	100%	121	100%	70	100%	17	100%
N/A	143				45			
χ^2	48.798				44.106			
df	1				1			
P<	0.0001				0.0001			

Analysis of the CCIS samples indicated a significant relationship between the injury severity and use of seat belts as shown in Table 4. From the analysis, belt usage did not prevent injuries in rollover, for serious to fatal injuries of belted FSOs in passenger cars and SUVs account for 26.1%, 12.9% respectively. But it decreased serious injuries, because more than 70% belted FSO in passenger cars and 87.1% belted FSO in SUVs only received slight injuries or no injury in pure rollovers. The risk of serious to fatal injuries of unbelted FSOs exposed to pure rollovers in SUVs is nearly 8 times that of the belted FSOs while the corresponding risk of unbelted FSOs in passenger cars is about 2 times that of the belted FSOs.

Unbelted occupants tended to receive serious to fatal injuries in rollover. Almost all of unbelted

FSOs in SUVs in pure rollover sustained serious to fatal injuries as they account for 94.1%. More than half unbelted FSOs in passenger cars also received MAIS 3~6 injuries.

Occupant ejection has long been considered to be an important contributor to death and serious injury in vehicle crashes [4]. Table 5 compares the risk of ejection for belted and unbelted FSOs in passenger cars and SUVs in pure rollovers. The likelihood of ejection for unbelted FSOs in pure rollover is higher than that of belted FSOs.

More than 95% belted FSOs in passenger cars and in SUVs were not ejected during a pure rollover. No belted FSO was ejected completely and only a few belted FSOs experienced partial ejection.

About 61% unbelted FSOs in passenger cars were ejected completely during a pure rollover, and almost all of unbelted FSOs in SUVs were ejected partially as they account for 94.1%. For FSOs in passenger cars, the risk of ejection of the unbelted is 13 times as that of the belted; And for FSOs in SUVs, the risk of ejection of the unbelted is 22 times as that of the belted.

Table 5 Comparison of Ejection for FSOs in pure rollover

Ejection	*FSOs in passenger cars in pure Rollovers*				*FSOs in SUVs in pure Rollovers*			
	Belted		*unbelted*		*Belted*		*Unbelted*	
No ejection	678	95.2%	40	33.1%	68	95.8%	1	5.9%
Complete	0	0.0%	74	61.2%	0	0.0%	0	0.0%
Partial	34	4.8%	7	5.8%	3	4.2%	16	94.1%
Total	712	100%	121	100%	71	100%	17	100%
N/A	125				44			
χ^2	482.025				65.468			
Df	2				2			
P<	0.0001				0.0001			

The *ejection routes* were compared in table 6. Side windows and sunroof were the main ejection routes for FSOs in passenger cars and SUVs. Side windows were also the most frequent apertures through which FSOs were ejected during a pure rollover.

Ejection tends to result in more severe injuries to the occupants. Table 7 compares the risk of an ejected FSO receiving a serious or fatal injury compared to that for a non-ejected FSO during a pure rollover. The incidence of being serious or fatal injuries was higher those FSOs who were ejected. Some 70 of the 114 ejected FSOs in passenger cars and 37 of the 40 ejected FSOs in SUVs received the injuries of MAIS≥3. Over three quarters FSOs in passenger cars and about 90% FSOs in SUVs who were not ejected only sustained slight injuries or no injuries.

Table 6 Comparison of Ejection Route for FSO in pure rollover

Belt Usage	*Ejection Route for FSOs in passenger Cars in pure rollover*	*Ejection Route for FSOs in SUVs in pure rollover*

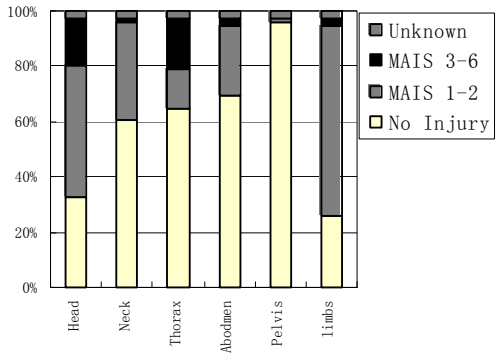
	Side window		*Sunroof*		*Unknown*		*Side window*		*Sunroof*	
belted	24	27.6%	0	0%	10	100%	3	8.8%	0	0%
unbelted	62	71.3%	19	100%	0	0%	16	47.1%	0	0%
U/N	1	1.1%	0	0	0	0%	15	44.1%	6	100%
Total	87	100%	19	100%	10	100%	34	100%	6	100%

Table 7 also compared the difference of *injury severity* from complete ejection and partial ejection. Complete ejection represents a higher risk receiving of serious to fatal injuries both in passenger cars and in SUVs as more than 80% complete ejected occupants received MAIS≥3 injuries. Most of FSOs in passenger cars experienced partial ejection received slight injuries no injuries, while more than 85% partial ejected FSOs in SUVs sustained MAIS≥3 injuries.

Table 7 Comparison of injury severity for Ejection of FSOs in pure rollover

Injury Severity (MAIS)	*FSOs in passenger cars in pure Rollover*						*FSOs in SUVs in pure Rollover*					
	No Ejection		*Complete*		*Partial*		*No Ejection*		*Complete*		*Partial*	
0-2	582	75.7%	11	14.9 %	33	82.5 %	79	89.8 %	0	0%	3	12.0%
3-6	187	24.3%	63	85.1 %	7	17.5 %	9	10.2 %	15	100%	22	88.0%
Total	769	100%	74	100%	40	100%	88	100%	15	100%	25	100%
U/A	75						4					
X^2	113.819						81.439					
Df	2						2					
P<	0.0001						0.0001					

Injury Distribution – Figure 5, 6 shows the injury distribution of FSOs in pure rollovers. Injury body regions of FSOs have the similar distribution both in passenger cars and SUVs. Pelvis has the lowest likelihood to get injuries both in passenger cars and SUVs, for more than 95% FSOs received no injury in pelvis. On the other hand, head and limbs are most possible to get injuries during pure rollovers, although limbs are inclined to get slight injuries. The head/face and thorax were the most frequently injured body regions for injuries of MAIS ≥3.



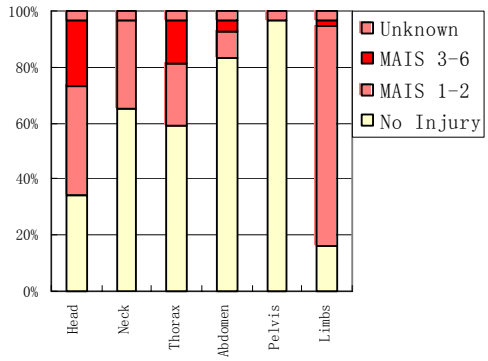


Fig. 5 Injury distribution of FSOs in Cars in Pure Rollover

Fig. 6 Injury distribution of FSOs in SUVs in Pure Rollover

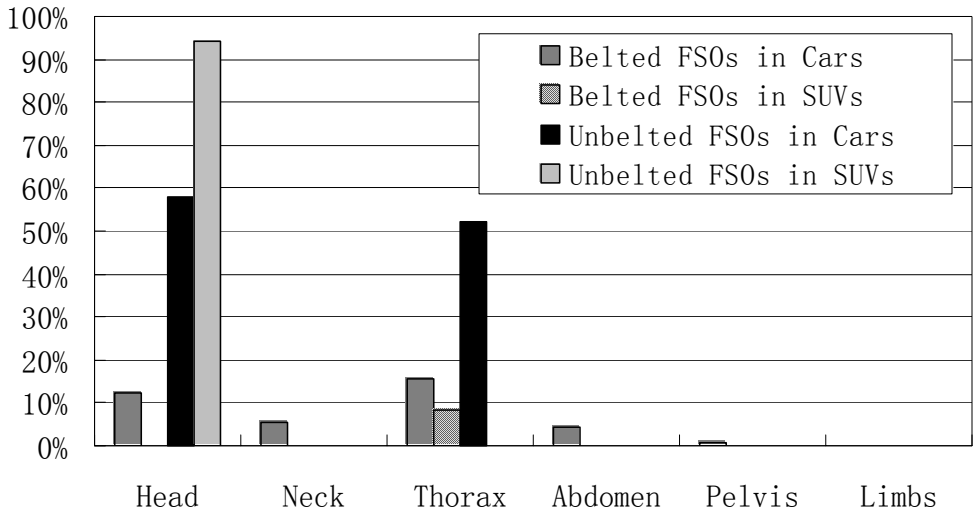


Fig. 7 MAIS ≥3 Injury distribution of front seat occupants in pure rollover

The detail comparison of serious to fatal injuries distribution between unbelted and belted FSOs in pure rollover is shown in Figure 7. The serious injuries mainly concentrated on head and thorax. Belted FSOs of passenger cars in pure rollover still have some possibility to receive serious injuries in the regions of head, neck, thorax, abdomen and pelvis, while only less than 10% FSOs of SUVs suffered thorax injuries of MAIS≥3.

Compared with belted FSOs, unbelted FSOs were more inclined to experience serious to fatal injuries. The MAIS≥3 injuries of unbelted FSOs in passenger cars were also concentrated on head and thorax, and more than 50% unbelted FSOs in passenger cars received head and thorax injuries of MAIS≥3. The proportions were nearly five times as those of belted FSOs which suffering serious to fatal injuries on head and thorax in passenger cars, respectively.

Most of unbelted FSOs of SUVs (more than 90%) suffered head injuries of MAIS≥3 while belted FSOs of SUVs hardly received serious head injuries.

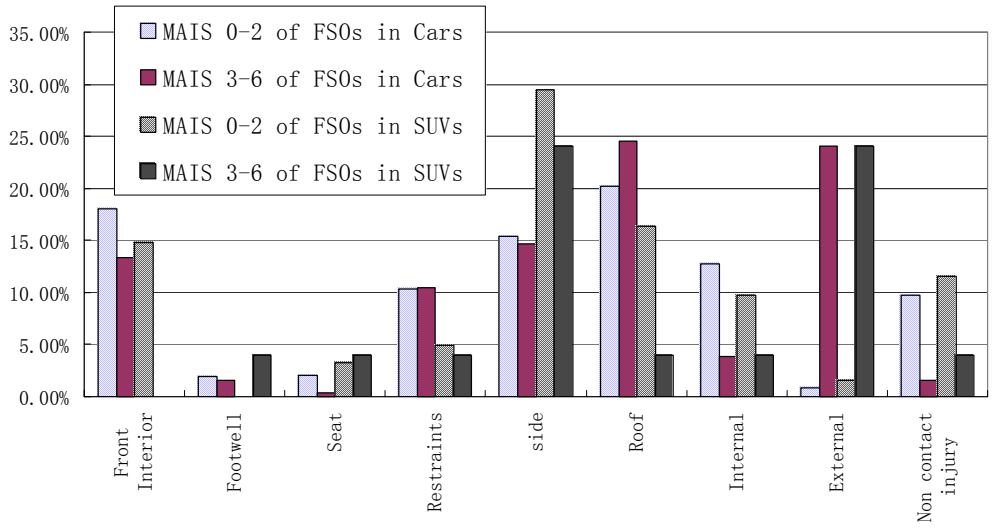


Fig. 8 Injury Causation of FSOs in pure rollovers

Injury Causation - Most of the injuries had an associated contact source. Figure 8 represents the injury causation of FSOs in pure rollovers.

For the FSOs received no or slight injuries, all possible contact areas, front interior (front panel, steering wheel), restraints(seat belt, airbag), side compartment (side doors, arm reset), roof and internal objects(animal, luggage), are the causations of slight injuries for FSOs in rollover.

External objects were the highest frequency of injury causation for the FSOs in passenger cars and SUVs suffering of MAIS≥3 injuries in pure rollover. It also proved that partial or complete ejection represents higher risk of injuries. Compared with other causation, restraints (seat belt and airbag) bring lower risk of serious injuries of FSOs both in passenger cars and in SUVs. It shows that FSOs can get the benefits from using restraints.

For FSOs in passenger cars, high frequent contact areas in pure rollover also possibly lead to serious injuries. That means those contact areas represent higher risk, such as front/interior (including front panel, windscreen, steering wheel as so on), restraints (seat belt and airbag), side compartment (door, arm rail and so on), and roof.

But for FSOs of SUVs, there is no such a significant relationship, because the causations of serious injuries (MAIS≥3) usually concentrate in external objects and side compartment.

Figure 9 shows the serious to fatal injuries causations of belted and unbelted FSOs in pure rollover. The injuries of belted FSOs in passenger cars mainly came from roof and side compartment while those of belted FSOs in SUVs were mostly from side compartment. Belted occupants still have a higher risk to receive serious injury That's because of seat belt couldn't prevent the right-left and upward motion of occupants in rollover. The FSOs in passenger cars have a smaller space compared to those in SUV, so the occupants' motion above mentioned within the rolling vehicle would lead to contact roof side compartment frequently and receive the injuries.

External objects such as tree, ground and so on, are highest likelihood injury causation for unbelted FSOs of passenger cars and SUVs in rollover. In fact, as one type of injury causation, external objects represent partial or complete ejection. It also shows that ejection means higher risk. Figure 9 also shows that roof was another important injury causation for unbelted FSOs in passenger

cars while side compartment was the important injury causation for unbelted FSOs in SUVs. Although Figure 9 doesn't show other detail injury causation for unbelted FSOs in SUVs, Table 4 has indicated that unbelted FSOs have higher possibility to receive serious to fatal injuries than belted FSOs in rollover.

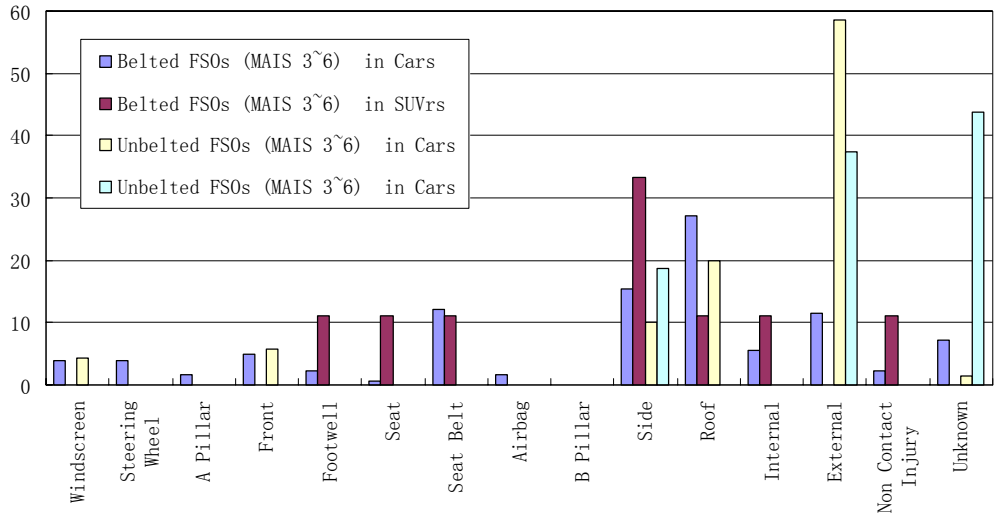


Fig. 9 Injury Causation of FSOs in pure rollovers

Roof Intrusion - From the Figure 8, the roof intrusion is an important causation for cars' occupant injury. From the Table 8, it's easy to find that most of occupants get injury slightly or no injury when the roof intrusion is small (0~20cm) both in passenger car and SUV. For FSOs in passenger cars, most of serious injury (MAIS>3) came with a deeper roof intrusion (>20cm). Actually, the degree of roof intrusion also represents the severity of impact. When the roof intrusion is deeper, the occupant space becomes smaller and it is easier to get injury.

For FSOs in SUV, there is no such an obvious relationship. That maybe SUVs have a bigger space compared with passenger cars and not easy to lead to a significant reduction of the life-saving space of the compartment.

Table 8 Roof Intrusion VS Injury severity of FSOs in pure rollover

MAIS	Passenger Car Roof Intrusion				SUV Roof Intrusion			
	0~20cm		>20cm		0~20cm		>20cm	
0~2	486	83.1%	187	54.2%	44	69.8%	18	75.0%
3~6	99	16.9%	158	45.8%	19	30.2%	6	25.2%
Total	585	100%	345	100.0%	63	100%	24	100.0%

4 Conclusion

The following conclusions arise from the study,

- Rollover crash was a more serious event for SUVs, as front and side impacts were serious events for passenger cars.
- Passenger cars had the similar proportion of roll to near side or off side while SUVs were inclined to roll to the off side.

- Belted front seat occupants in passenger cars and SUVs may obtain some benefits in pure rollovers, as belt can help to prevent ejection and serious to fatal injuries.
- Side windows and sunroof were main ejection routes for FSOs in passenger cars and in SUVs, during pure rollover.
- The head/face and thorax regions were most frequently injured body region for injuries of AIS >=3.
- External objects were the highest frequency of injury contact for front seat occupants both in passenger cars and SUVs.

5 Acknowledgement

CCIS is managed by TRL limited on behalf of the Department of the Environment, Transport and Regions (Vehicle Standards and Engineering Division) who fund the project with Autolov, For Motor Company, Honda R&D Europe, LAB, Toyota Motor Europe and Volvo Car Corporation. The data were collected by teams from the Birmingham Automotive safety Centre of the University of Birmingham; the Vehicle Safety Research Centre of the University of Loughborough; Vehicle Inspectorate Executive Agency of the DETP. Furth information on CCIS can be found at http://www.ukccis.org/

6 References

1. Rollover European Commision 5th Framework Program: Improvement of Rollover Safety for Passenger Vehicles. [online]. Available from:http://www.mechanik.tu-graz.ac.at/rollover/ Click on 'About' [Accessed 4 March 2004]
2. A.M.Hassan, M.Mackay, 'Intrusion Resistant Glazing, Implication for Vehicle Occupant Safety', 4th Malaysian Road Conference, Kuala Lumpur, Malaysia, 2000.
3. AAAM(1990). The Abbreviated Injury Scale 1990 version. American Association for Automotive Medicine. Arlington Heights. Illinois.
4. Campbell, B.J., 'A Review of ACIR Findings', 8th Stapp Car Crash and Filed Demonstration Conference, 1966.
5. Chantal S. Parenteau, Minoo Shah, Driver Injuries in US Single-Event Rollovers, SAE 2000 World Congress, Detroit, Michigan, USA, 6-9 March,2000
6. A.M. Hassan, M.Mackay, Yngve Haland, Rollover Experience with sport utility vehicles, 5th World Conference on Injury Prevention and Control, 5-8 March, New Delhi, India. 200.
7. Kennerly Digges, A.C.Malliaris, Crashworthiness Safety Features in Rollover Crashes, International Body Engineering Conference and Exposition, Detroit, Michigan, USA, 09/29 to 10/1 1998
8. Mackay,G.M., Galer, M.D., Ashton, S.J., Thomas, P.,(1985), The Methodology of In-depth Studies of Car Crashes in Britain. SAE Technical Paper Number 850556, Society of Automotive Engineers.
9. Hassan, AM., Mackay, M., Foret-Bruno, J-Y., Huere, J-F., and Langwieder, K. "Laminated Side Glazing - Implications for Vehicle Occupant Safety". 2001 International IRCOBI Conference on the Biomechanics of Impact, pp 283 - 294.