SESSION 5 :
OLDER DRIVER

EFFECT OF AGE ON INJURY OUTCOME IN PASSENGER CAR FRONTAL CRASHES

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ABSTRACT: The senior population is growing rapidly across most motorised countries resulting in an increasing number of elderly motor vehicle users. Accident data from the UK Cooperative Crash Injury Study (CCIS) were analysed to examine the relationship between age and injury outcome for belted front seat occupants in passenger car frontal crashes. Results showed that, for similar frontal crash characteristics, the MAIS outcome was more severe for older front seat occupants (65+) and they were more likely to be fatally injured compared to middle-aged and younger occupants. The chest was the most frequently injured body region. The older occupants sustained more injuries to the chest region compared to their younger counterparts and these injuries were predominately skeletal injury induced by seat belt forces. Older occupants had a higher rate of multiple rib fractures compared to younger and middle aged occupants. The increase in the number of rib fractures showed a strong association with increase in intrathoracic organ injury. These results suggest that older occupants are more vulnerable to serious injury to the chest region in frontal impacts. Vehicle crashworthiness systems that account for differences in age related injury tolerance could have a positive effect on injury outcome in frontal car crashes.

Keywords : Real world accident, Injury risk, Elderly Occupants, Accident Analysis

1 INTRODUCTION

For some time now, the safety community has been questioning the effectiveness of occupant protection for elderly vehicle occupants. This is in part due to recognition of the major shift in the population distribution in most motorised countries. The number of older people in the European Union is projected to grow dramatically over the next two decades and beyond (Zaidi 2008). It is predicted that by 2050, the proportion of older people (65 years and above) in Europe will be close to 30 % compared to 21% in 2000 (Zaidi 2008). In the US by 2030, 19% of the population will be aged 65 or over (Ridella et al. 2012). Similarly, in Australia the proportion of older persons aged above 65 years is projected to rise from 11.1% in 2001 to 24.2% in

2051 (Australian Bureau of Statistics 2006).

Mobility is a critical factor to carry out life's activities and in most western countries private passenger cars satisfy this need (Oxley et al. 2010). As their population grows, it is expected that the number of older people using passenger cars will be greater than ever before. In the UK, more than 4 million adults above 70 years old are currently licensed. It is predicted that 40 million older adults (65 years and above) will be licensed in the US by the year 2020, compared to 19.9 million in 2002 (Dellinger et al. 2002). Research in the US by Hu et al. (2000) estimates that over the next three decades, without active interventions, the number of fatal crashes involving older car occupants could be increased as much as three times compared to the present. The anticipated increase in the fatality involvement rate is also reported in other earlier studies (Lyman 2002; Insurance Institute and Highway Safety 2002).

In addition to an increase in elderly road users their increased injury probability is important. It is generally acknowledged that age is an important factor in the injury outcome in a vehicle crash. The European road safety report (DaCoTA 2011) shows that in the year 2009, almost 7000 elderly people (>64 years) died in road traffic accidents, accounting for more than one-fifth of the total fatalities. Older occupants differ from young or middle age occupants in several respects including physiological tolerance, injury outcomes and crash exposures (Islam & Mannering 2006; Kent et al. 2009). Previous studies have shown that the biomechanical tolerance to injury declines with age, reducing the ability for the body to withstand blunt trauma (Augenstein 2001; Welsh, Morris, Hassan, et al. 2006; Dejeammes & Ramet 1996). Also, elderly are frail than younger, the relative risk of severe outcomes for the same injury increases with ageing (Kent et al. 2009).

The objective of the present study was to analyse the UK in-depth real world accident data to examine the effect of age and other confounding factors on injury severity outcomes for belted front seat occupants in frontal passenger car crashes.

2 METHODS

The UK Co-operative Crash Injury Study (CCIS) data collected between 1998 and 2009 were used in this study. CCIS collected in–depth crash and injury information from selected geographical regions representing urban and rural roads in Great Britain (Mackay et al. 1985; Hassan et al.1995). An accident was included in the sample if (a) it occurred in one of the specified sample regions, (b) at least one occupant of a passenger car (7 years old or less at the time of the crash) was injured according to the police assessment, and (c) the vehicle was towed from the accident scene. The database contained detailed information on vehicle crash severity estimated by the Equivalent Test Speed (ETS), structural performance and restraint performance together with photographic documentation of the vehicle exterior and interior along with forensic evidence relating to the injury causation. The ETS is evaluated on the assumption that the vehicle deformation was caused by an impact with a rigid, immovable object (Lenard, Hurley, et al. 1998).

The study investigated some 80% of serious and fatal and 10–15% of slight injury crashes in the sample regions. Consequently, the slight injury records were underrepresented in the data that were biased toward more serious crashes. Weighting factors based on sampling percentage were applied to the data in order to give a representative population of crashes. The injury outcome was recorded using the Abbreviated Injury Scale (AIS; Association for the Advancement of Automotive Medicine 1990). The criteria used to select the frontal impact population are shown below:

- Single frontal crash or 2 impacts with frontal impact being the most significant in causing injuries.
- No underride and Non rollover crashes.
- Principal direction of force between 11 and 1 o’ clock.
- Vehicles manufactured after the calendar year 1995.
- Three-point belted front seat occupant ≥15 years of age.

- Vehicle with frontal airbag and seat belt pretensioner.

The unweighted accident sample consisted of 2,644 front seat occupants. Applying weighting factors gave 7,729 front seat occupants consisting of 6,644 (86%) drivers and 1,085 (14%) front seat passengers (FSP). For all statistical tests, the significance level was set at a 95% confidence level ($p<0.05$). The occupant age was broadly categorised into three groups namely: a) young: 15-39 years, middle- aged: 40-64 years and c) old: 65+ years. This classification was based on similar European real world accident studies (Welsh, Morris, Hassan, et al. 2006; Morris et al. 2003).

3 RESULTS

3.1 General Sample Characteristics

3.1.1 Vehicle Manufacture Year: In the sample, 44% of the vehicles were manufactured pre-2000, 50% were manufactured between 2001 and 2006 and 6% of the vehicles were manufactured after 2007. Figure 1 shows the distribution of the vehicle manufacture year for the sample.

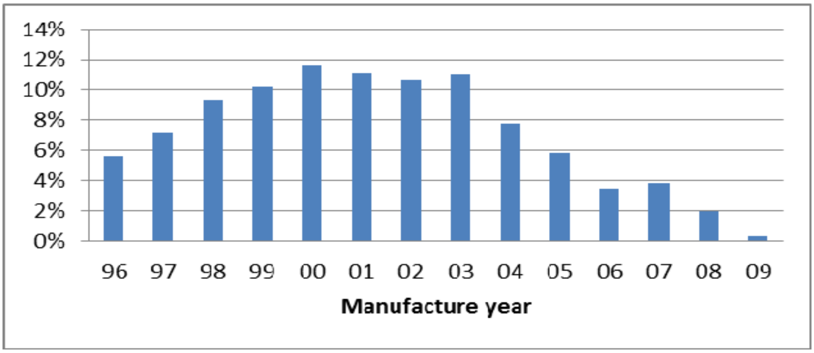

Figure 1 Vehicle Manufacture year

3.1.2 Occupant Age: Figure 2 shows the distribution of age by seating position. More than half of all occupants (53%) were aged between 15 and 39 (young), 35% of all occupants were aged between 40 and 64 (middle-aged) and 12% of all occupants were aged over 64 (elderly). The proportion of elderly occupants in the front passenger seat was greater than the driver seat. The mean age of the occupants in the front passenger and driver seat was 42.2 and 40.6 years respectively, which was statistically different when compared by using Independent Samples T-test ($p<0.05$).

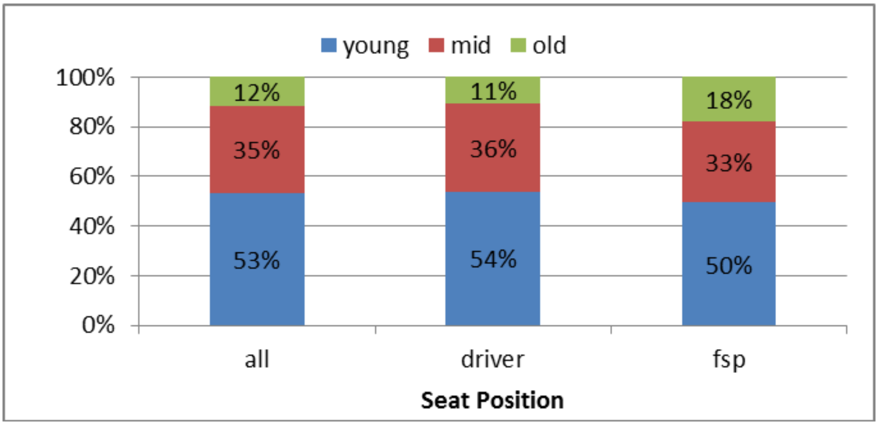

Figure 2 Age group by seating position

3.1.3 Occupant Gender: Overall, 59% (4553) of occupants were male and 41% (3176) were female. Unlike the driver sample where a majority of the occupants were male (63%), front seat passengers were mostly female (65%).

3.1.4 Crash Severity by seating position: From Figure 3, it can be observed that the distribution of crash severity was very similar between the two front seat occupant groups. The majority (66%) of impacts occurred between 20 and 45km/h. The ETS for 97% of all impacts were below 50 km/h and 99% occurred below 60km/h.

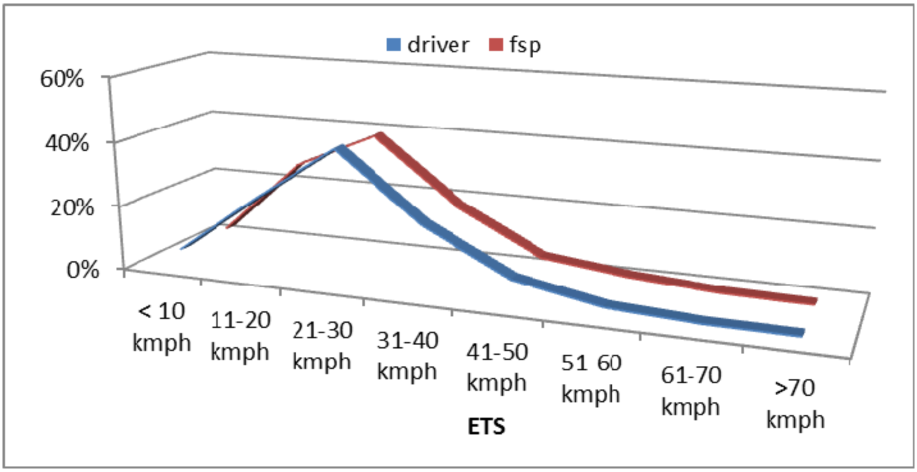

Figure 3 ETS distributions by seating position

3.1.5 Crash severity by seating position and age: Table 1 compares the crash severity between age groups using the mean ETS. Small observational differences are apparent in the mean ETS shown in Table 1; however none of these were significant ($p>0.05$).

Table 1 Mean ETS by seating position and occupant age

	Mean ETS (km/h)		
Seating Position	<40 (Young)	40-64 (Middle-aged)	65+ (Old)
Driver	26.99	26.22	26.43
FSP	26.43	25.25	26.02

3.1.6 Dashboard Intrusion: Of all occupants, 90% had intrusion below 3cm, 4% had sustained intrusion between 3 and 9cm, and 4% sustained intrusion greater than 10cm. The intrusion level was not known for 2% of the sample.

3.1.7 Maximum Abbreviated Injury Severity (MAIS) by Seating Position: The MAIS represents the overall injury severity to an occupant. Table 2 shows the distribution of MAIS by seating position for all front seat occupants (driver and FSP). The proportion of front seat passengers with MAIS 2 and MAIS 3+ injury were greater than drivers. Chi Square test showed a significant relationship between injury severity outcomes and front seating positions ($\chi 2 = 35.52$, d.f $=2$, $p<0.05$).

Table 2 Injury Severity Outcome for Front Seat Occupants

	Front Seating Position		
Injury Severity	Driver	Front passenger	All occupants
MAIS 0,1	84.6%	77.9%	83.7%
MAIS 2	10.1%	15.7%	10.9%
MAIS 3+	5.3%	6.4%	5.4%

3.1.8 Injury severity outcome by age: Figure 4 illustrates the MAIS outcome according to occupant's age. In the sample, older occupants were over-represented at all levels of injury severity from MAIS 2 and above. The injury risk to middle- aged occupants from MAIS 2 and above was greater than for young occupants. A chi square test found that the overall distributions of injury outcomes across the three age groups varied ($\chi 2 = 226.20$, d.f =12, $p<0.05$).

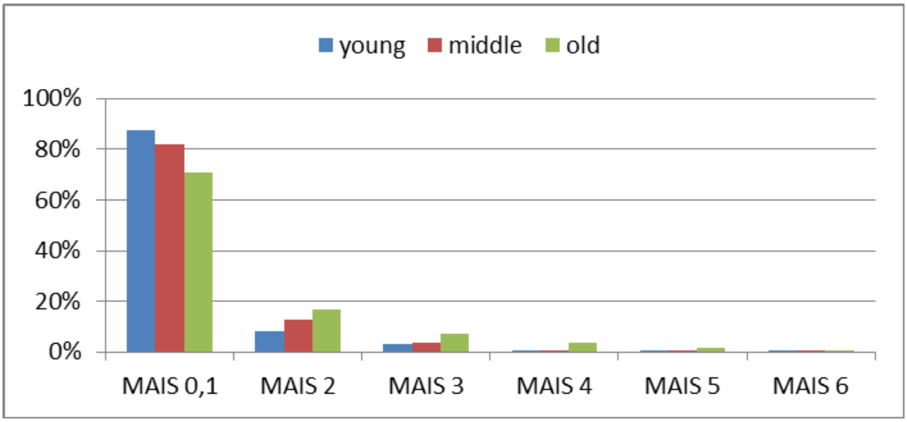

Figure 4 Injury severity by age group

3.1.9 Injuries by Body Region: Table 3 shows the rate of occupant injury severity by body region, for all occupants in the sample. Injuries to the head at the AIS 2+ level were received by 177 occupants (2.3%). Only 1% of occupants had neck injury at the AIS 2+ level. The chest was the most frequently injured body regions at all AIS severity levels. 524 (6.8%) of all occupants had AIS 2+ chest injury. Around 2% of all occupants had sustained at least one AIS 2+ abdomen injury. The second most frequently injured body region at the AIS 2+ level was the upper extremity (6.3%) followed by the lower extremity (5.9%). None of the injuries to the extremities were rated at AIS level 4 or above.

Table 3 Injury Severity frequency for each body region

	Head	**Neck**	**Chest**	**Abdomen**	**Upper Ex.**	**Lower Ex.**
AIS 2+	2.3% (N=177)	1% (N=77)	6.8% (N=524)	2.2% (N=171)	6.3% (N=488)	5.9% (N=457)
AIS 3+	1.1% (N=83)	0.2% (N=17)	2.6% (N=202)	0.7% (N=53)	1.0% (N=77)	2.5% (N=195)
AIS 4+	0.5% (N=37)	0.0% (N=3)	1.1% (N=84)	0.2% (N=13)	0.0% (N=0)	0.0% (N=0)

3.2 Chest Injury

3.2.1 Chest Injury rate by Seat Position: The maximum chest injury severity by seating position is shown in Figure 5. 414 drivers and 110 front seat passengers had chest injuries at the AIS 2+ level. The rate of chest injury for front seat passengers was higher than for drivers at all injury severity levels. The rate of AIS 2+ and 3+ chest injury for the front seat passenger was 10% and 4% respectively. The injury severity rates for front seat passengers were greater than for drivers by 1.5 times (AIS 2+) and two times (AIS 3+) respectively.

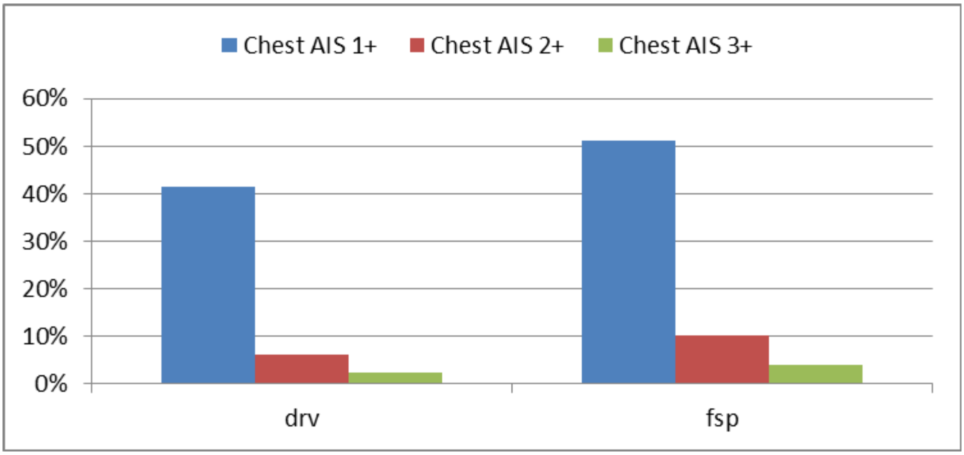

Figure 5 Chest injury severity by seating position

3.2.2 Chest Injury Rate by Age: Figure 6 shows the rate of AIS 2+ and AIS 3+ chest injury for occupants by age group. The rate of injury at both severity levels increased with the age. The rate of AIS 2+ injury for younger, middle aged and older occupants was 2% (n=100), 10% (n=272) and 17% (n=153) respectively. 1% of younger occupants (N=52), 3% of middle- aged occupants (N=76) and 8% of elderly occupants (N=75) had sustained at least one AIS 3+ chest injury.

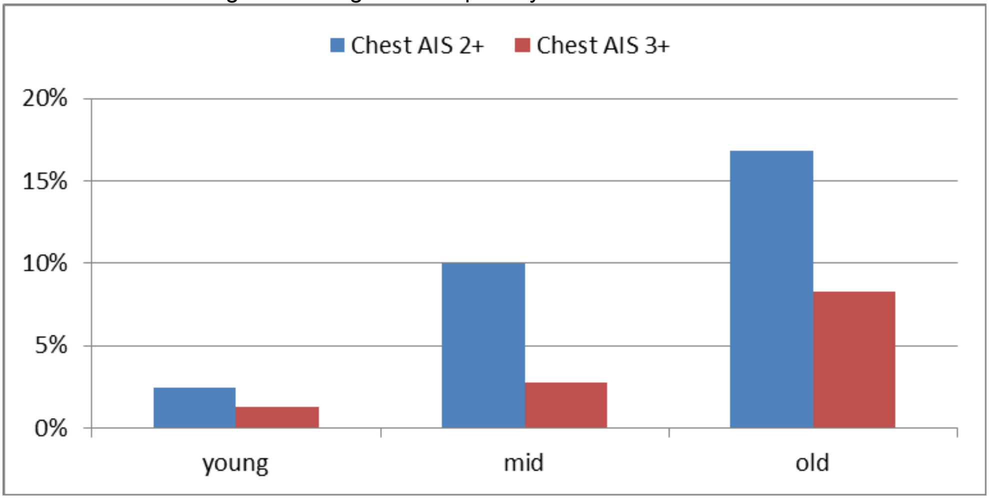

Figure 6 Rate of chest injury by age

3.2.3 Crash Severity of chest injured occupants by age group:

In the sample, 211(40%) of all AIS 2+ chest injured occupants had sustained their injury with ETS less than 30km/h and 71% below 40 km/h. The rate of AIS2+ chest injury at ETS less than 30km/h was 0%, 6% and 12% for younger, middle-aged and older occupants respectively. Considering ETS above 50km/h, the rate of AIS 2+ chest injury to younger, middle-aged and older occupants were 19%, 44% and 58% respectively.

The mean ETS of AIS 2+ and 3+ chest injured occupants by age are listed in Table 4 . The mean ETS of AIS 2+ chest injured older front seat occupants (32.2 km/h) was less than that for younger (44.6km/h) and middle aged (32.4km/h) occupants. Similarly, the mean ETS of AIS 3+ chest injured older occupants (36.7 km/h) was less than the younger (50.0 km/h) and middle aged (45.4 km/h) occupants. One-way analysis of variance (ANOVA) tests found a significant difference in the mean ETS between age groups ($p<0.05$), for occupants who had sustained AIS 2+ and AIS 3+ level chest injuries.

Table 4 Mean ETS of the occupants injured in chest by age group

	Mean ETS (km/h)		
	Young	**Mid**	**Old**
Chest AIS 2+	44.6	34.4	32.2

Chest AIS 3+	50.0	45.4	36.7

3.2.4 Type of AIS 2+ chest injury: There were 714 AIS 2+ chest injuries recorded in the sample (**Erreur ! Source du renvoi introuvable.**). Some of the occupants had more than one AIS 2+ chest injury. If an occupant had skeletal fracture and pulmonary complications such as pneumothorax, haemothorax, haemo-pneumothorax and flail chest, then the injuries were counted as a single injury. Skeletal injuries were the most common type of AIS 2+ chest injuries, followed by the intrathoracic organ and vessel injuries. The recorded numbers of injuries to the thoracic skeletal, organ and vessel were 514 (72%), 175 (24%) and 25 (4%) respectively. Sternum fractures made up a large proportion of all AIS 2+ chest injury occurring in 337 occupants, of which 325 had sternum fracture with a stable chest. Multiple rib fracture with more than 4 fractured ribs was the second most common type of skeletal chest injury occurring in 108 occupants. 53 occupants had fractures to 2 or 3 ribs. The number of fractured ribs for 8 occupants was unknown. Injury to the lungs was the most common type of intrathoracic organ injury, 84 such injuries were recorded in the sample. Lung contusion was the most common type of lung injury and was mostly rated at AIS 3 or 4 levels. Injury to the heart (n=16) was the second most common type of intra-thoracic organ injury followed by injury to the pericardium (n=15) and diaphragm (n=10). Other intrathoracic organ injuries occurred for fewer occupants. All injuries to the heart were rated at AIS 3+ level, and 5 of those injuries were critical-fatal injuries (AIS 5 or AIS 6). Vessel injuries were most likely to be rated at AIS 4+ level and occurred more sporadically. Injury to the aorta (n=20) was the most common type of vessel injury in the sample.

3.2.5 Contact source of AIS 2+ Chest Injuries: Of 524 occupants with AIS 2+ chest injury, 377 (73.3%) had one or more chest injuries solely due to the seat belt loading. For a further 17.6% of occupants, injury was caused by the steering wheel. In 5.5% of occupants, AIS 2+ chest injury was entirely due to another source such as airbag, door, and vehicle interior panels. The remaining 3.6% of occupants had chest injuries caused by a combination of loading.

3.2.6 Contact Source of AIS 2+ Skeletal Injuries: The distribution of source of contact for all skeletal fractures in the sample is shown in Figure 7. The seatbelt was the single major source of contact for all skeletal fractures. 76% of all skeletal fractures were caused by the seat belt, 19% were from the steering wheel and 5% from other sources. The seat belt was the source of injury for 89% of the sternum fractures, 74% of the single rib fractures and 56% of the 2-3 rib fractures. The difference in the proportion of steering wheel (42%) to seat belt (49%) as a source of injury for 4 or more rib fractures was relatively small compared to the source distribution for other types of injury.

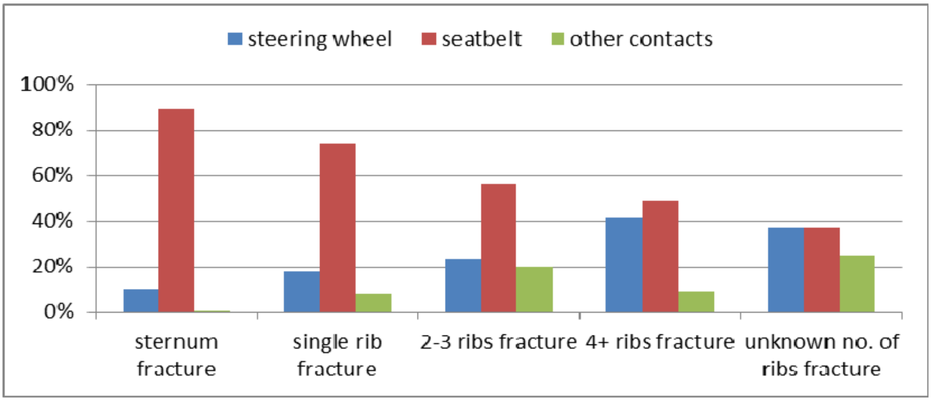

Figure 7 Source of contact for skeletal fractures

3.2.7 Rate of Skeletal Fracture by Age: The rate of sternum and rib fracture for all front seat occupants is shown in Figure 8. Some of the occupants had both sternum and rib fractures. In total, 604 skeletal fractures were reported in the sample. Sternum and rib fractures were most common with the older occupants and least common with the younger occupants. 25% of the older occupants had sustained sternum fracture compared to 22% for middle aged and 3% for younger occupants. 15% of the older occupants had reported with 4 or more rib fractures, which was the second most common type of skeletal fracture among the elderly occupants.

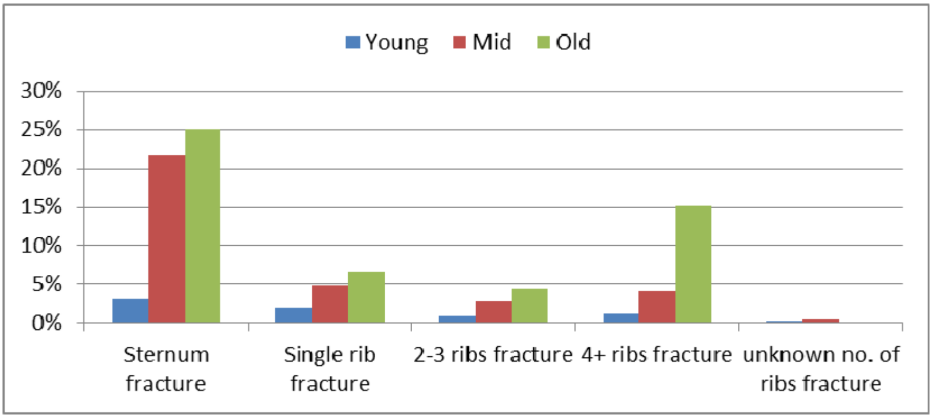

Figure 8 Rate of skeletal fracture by age

3.2.8 Injured intra-thoracic organs and fractured ribs: Figure 9 shows a strong association between organ injury and number of rib fractures. The majority of lung injuries (54%) were associated with 2 or more rib fractures, while 38% of the lung injuries were associated with 1 or no rib fracture. More than half of all injuries to each organ were associated with 2 or more rib fractures. More than 90% of all pericardium and pleural sac injuries were associated with 2 or more rib fractures.

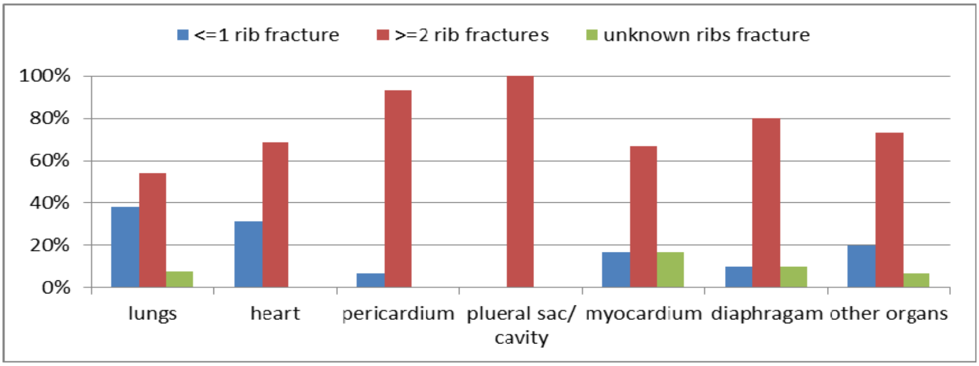

Figure 9 Association of chest organ injury with number of rib fractures

4 DISSCUSSION

In the data sample, the proportion of elderly occupants in the front passenger seat was higher compared to the driver seat (18% compared to 11%). The driver seat had the highest proportion of younger occupants, 54% were below 40 years of age. Differences in the gender proportion were observed between the two front seating positions. The majority of the drivers were male (63%). Despite being the minority in the overall sample, the proportion of females outnumbered the proportion of males on the passenger side. These findings suggest that the front passenger seat position is more frequently occupied by females and older occupants.

The crash severity in this study was determined by the Equivalent Test Speed (ETS). There was no significant difference in the mean ETS between the both front seating positions. The mean ETS between age groups in both seating positions was almost similar, suggesting in general, the crash severity experienced by different occupant age groups was similar.

Only 2% of the occupants in the data sample had sustained AIS 2+ head injury. This indicates the protection offered by modern vehicles to the head region in frontal impacts is generally good, concurring with earlier real world studies (Lenard, Frampton et al. 1998; Frampton et al. 2002; Frampton et al. 2006; Kirk et al. 2002). There were few neck injuries rated at the AIS 3+ level, suggesting that serious and life threatening neck injuries are not common in frontal crashes. The chest was the most often injured body region at AIS 2+ injury levels. A high frequency of severe chest injury in frontal impacts is reported by several authors (Kitagawa & Yasuki 2013; Ridella et al. 2005; Brumbelow & Zuby 2009; Lenard, Frampton, et al. 1998; Welsh, Morris, Frampton, et al. 2006). In this study, the chest was found to sustain higher rates of AIS 4+ injury than any other body region and this is similar to previous findings (Frampton et al. 2006). A high frequency of injuries to the lower extremities in frontal crashes were reported with earlier studies (Morris et al. 2006; Austin 2012; Rudd 2009; Welsh, Morris, Frampton, et al. 2006) but these are rarely life-threatening (Read & Kufera 2004). In the sample, lower extremity injuries were the second most frequent followed by the chest region when considering AIS 3+ type injuries. Although none of them were life threatening, these results suggest that along with chest injuries, there is still a need to reduce injuries to the lower extremities in frontal impacts.

The older occupants in the sample were most at risk of sustaining severe injuries. They were overrepresented at MAIS 2, 3 and 4+ levels. This result verifies the continuing vulnerability of older occupants to serious injuries in frontal impacts, concurring with earlier real world studies using CCIS data (Morris et al. 2003; Welsh, Morris, Hassan, et al. 2006). This is also consistent with several US real world accident studies (Kent et al. 2009; Carter et al. 2014; Ridella et al. 2012).

There appeared to be a significant relationship between age and chest injury outcome. The rate of AIS 2+ and AIS 3+ chest injuries was highest among the older occupants and lowest among the younger occupants. Moreover, older occupants tended to sustain proportionally more severe chest injuries in low/moderate speed impacts compared to the other two occupant groups. This is in agreement with previous studies (Augenstein et al. 2005; Welsh et al. 2006; Mertz & Dalmotas 2007). Younger occupants tended to receive proportionally less AIS 2+ chest injuries even in severe accidents. In impacts with ETS above 50km/h, only 20% of the younger front seat occupants had sustained AIS 2+ chest injuries, whereas the corresponding rate of injury for middle aged and older occupants were 44% and 58% respectively.

Despite similar crash severity between seating positions, the rate of MAIS 2 and 3+ injury sustained by front seat passengers was significantly greater than for drivers. Similarly, the rate of AIS 2+ and 3+ chest injury to passengers was greater than that for drivers. The apparent difference in the injury risk between the two seating positions in this study could be due to an overrepresentation of older, female occupants who are generally more susceptible to serious chest injuries than their younger male counterparts. This finding agrees with Carroll et al. (2009) who reported that the restraint systems are better optimised for the drivers than for the passengers, suggesting potential scope for improvement to the front passenger restraint system. Perhaps the most concerning aspect of this result is that the situation has remained unchanged for many years, despite significant improvements to occupant protection in other areas. The chest injury risk for older females in the front passenger seat, in frontal impact was highlighted more than 20 years ago (Frampton and Mackay, 1994).

Skeletal injury was the most frequent type of AIS 2+ chest injury. Injuries to intrathoracic organs were the second most frequently occurring AIS 2+ chest injuries followed by injuries to vessels. Skeletal injury mainly comprised of sternum and rib fractures. Sternum fracture, 4 or more fractured ribs and lung contusion was the most frequent injury type in the sample. This is also consistent with previous CCIS analyses (Welsh, Morris, Frampton, et al. 2006; Hill et al. 1994). Sternum fractures are usually coded at AIS 2 level. They are generally less severe when occurring alone and are less likely to cause any further complications (Breederveld et al. 1988; Brookes et al. 1993). 56% of the occupants with 4+ rib fractures had no other pulmonary complications but the other 44% of occupants had sustained pulmonary complications such as haemothorax and/or pneumothorax. The lungs were by far the most frequently injured intra-thoracic organs. This was followed by the heart and the pericardium. Injuries to vessels were less common in the sample, however, those injuries are mostly rated at the AIS 4+ level, and are possibly life threatening, so should not be disregarded based on a low frequency of occurrence.

The rate of injury for older occupants with skeletal injuries (sternum, single rib, 2-3 rib and 4+ rib fractures) was higher than for the other two age groups. Particularly, the difference in the rate of sternum and 4+ rib fractures to older occupants was higher compared to the younger occupants. Several studies associate this increased risk of skeletal injuries among older occupants to the biomechanical changes due to the ageing process. It is already an established fact that as a person ages, demineralisation of bone occurs which makes the bone more porous and reduces the material strength (Cowin 2001). Kent and Patrie (2005), reported that the 50% risk of sustaining 6+ rib fractures for 30 a year old was at a chest deflection of 43% of its depth, but a 70 year old can only tolerate 33% of the chest deflection for the same level of injury risk. Kent et al. (2005) found, with ageing, the rib cage tends to get narrower and deeper, and the thickness of the cortical bone layer reduces. They associated these geometrical changes to increased rib fractures for the elderly. The combined effects of these biomechanical changes tend to reduce the rib fracture tolerance and in the presence of several other comorbid factors, means that older people tolerate less force before such injury occurs (Kent et al. 2008). Furthermore, fracture to ribs and sternum were mostly caused by the seat belt loading, clearly suggesting there is a need to manage restraint forces in frontal impacts.

This study was also extended to look at the relationship between rib fractures and the occurrence of intrathoracic injuries. With the increase in the number of rib fractures, the risk of pulmonary complications and organ injuries tended to increase, concurring with previous studies (Sirmali et al. 2003; Kent et al. 2008; Thor & Gabler 2008). To understand the nature of the injury occurrence for the different age groups, the crash severity of such injury types should be further studied. Such analysis could give an association between the crash severity (i.e. magnitude of the force experienced) and the number of rib-intrathoracic injuries.

If predictions for the demographic shift in populations toward the elderly are correct, this study shows the necessity for safety interventions, through new vehicle crashworthiness systems to improve chest protection for elderly occupants. Several studies have reported that intelligently varying the restraint deployment characteristics by accounting for differences in age related injury tolerance may better manage the restraint forces acting on the chest in frontal crashes (Ekambaram et al. 2015; Hynd et al. 2011; Bosch et al. 2005). Ekambaram et al. (2015) estimated the real world injury reduction benefit of smart/adaptive load limiters by applying numerical crash simulations results to the real world accident database (CCIS). They reported that, if the vehicles in the accident sample were fitted with the smart load limiters, the risk of sustaining an AIS 2+ chest injury may decrease by 5% and 2.7% for the older and middle-aged front seat occupants respectively in frontal impacts.

5 CONCLUSIONS

- The front passenger seat was most frequently occupied by females and elderly (>64 years) compared to the driver side.
- Chest injury severity outcome for front passengers was proportionally higher than for drivers.
- The chest was the most frequently injured body region at AIS 2 and above levels.
- Despite similar crash impact severity between age groups, older occupants tended to sustain more severe MAIS and chest injury outcomes compared to their younger counterparts.

- Skeletal fracture was the most frequent type of AIS 2+ chest injury and was mostly caused by seat belt loading.
- The rate of sternum and rib fractures for elderly occupants was substantially higher than for younger occupants.
- The increase in the number of rib fractures had a strong association with the risk of intrathoracic organ injury.

6 ACKNOWLEDGEMNTS

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RELATIONS BETWEEN ELDERLY DRIVERS COGNITIVE FUNCTIONS AND THEIR COMPENSATORY DRIVING BEHAVIORS

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ABSTRACT: We investigated the relationships among elderly driver's cognitive functions, self-monitoring about the driving capability, and the attitudes to compensatory driving behaviors. 100 participants' (age range: from 50 to 78 years old) cognitive functions were measured using Advanced Industrial Science and Technology's Cognitive Aging Test (AIST-CAT). The questionnaires were applied to a collection of the participants' self-awareness changes in driving capabilities and collection of the compensatory behaviors in their daily drives. Bayesian network modelling contributed to assessing the relations between the measured three responses. The modelling results sugget that "Planning" in the AIST-CAT influences "Avoiding violation of traffic rules" in the compensatory behaviors and "Visual attention" in the AIST-CAT influences "Changes in ability to execute driving operations" in the self-awareness changes of functional declines. The findings imply the cognitive functions of which elderly drivers become conscious.

1 INTRODUCTION

Driving expands the activities and enhances the quality of life of elderly people. Cognitive and physical functional declines of elderly drivers may lead to increased traffic accidents. Several research has suggested elderly driver's compensatory strategies, including choosing lower driving speeds and avoiding bad weather conditions, which are adapted to their functional limitations [1]. Advanced driver assistance systems should support the elderly driver's behavior that are out of range of the compensatory strategies, because the elderly driver's acceptance may be low if the assistance systems would be intended to support the behaviors within the compensatory strategies. Investigating the relationship between the elderly driver's cognitive and physical functions and their compensatory driving behaviors is expected to understand the causes of taking the compensatory strategies.

Self-awareness of the functional limitations by the elderly also influences the elderly driver's willingness to take the compensatory behaviors. Prof. Anstey suggested schematic model of the factors enabling safe driving behavior, where the self-monitoring and beliefs about driving capacity influence the driving behavior and the self-monitoring and beliefs are influenced by the drivers' cognition [2]. The important factors among the cognitive abilities were not clarified, which affect the compensatory driving strategies of elderly drivers and their consciousness of the age-related functional declines.

In this study, we investigated the relations between elderly driver's cognitive functions, their self-awareness of the functional declines, and their compensatory strategies. Experiments using cognitive test sheets and two kinds of questionnaires were conducted. The relationships were investigated using the Bayesian network modelling technique.

2 METHODS

2.1 Participants

100 drivers participated in the experiments. Average age was 64.5 years old (from 50 to 78 years old). Average driving experiences were 39.2 years (from 3 to 57 years). Almost all of them drive their own vehicles more than once a week. The on-site experiments consisted of the following three sessions: Advanced Industrial Science and Technology's Cognitive Aging Test (AIST-CAT), Questionnaire on self-awareness changes in cognitive and physical functions while driving, and Questionnaire on compensatory driving strategies.

2.2 Procedures: AIST-CAT

The AIST-CAT is a test battery for measuring the decline of cognitive functions in healthy elderly adults who are neurologically normal. The test consists of a working memory task, a visual attention task, a planning task, and a task-switching task [3]. Figure 1 presents the overall of AIST-CAT.

In the working memory task, participants were asked to write the mirror image of Japanese "hiragana" letters, which were printed on a test sheet. The number of letters written correctly within one minute was scored.

In the visual attention task, participants were asked to select the same figures in the test frame as the target figure that was printed above the frame. They were instructed to check as many figures as possible within one minute. The number of the figures, which were correct, was scored. We subtracted the number of distractors, which the participants checked by mistake, from the total scores.

In the planning task, participants were asked to describe a familiar daily activity in correct order. The first and last steps were printed on a test sheet. They were instructed to fill in the missing action steps within three minutes. The score was calculated based on the number of the reported critical steps, which were defined in advance.

In the task-switching task, participants were asked to select either number based on the character between the numbers. They were instructed to check larger “number” if the center character was “number”, and to check larger “letter” if the center character was “shape”.

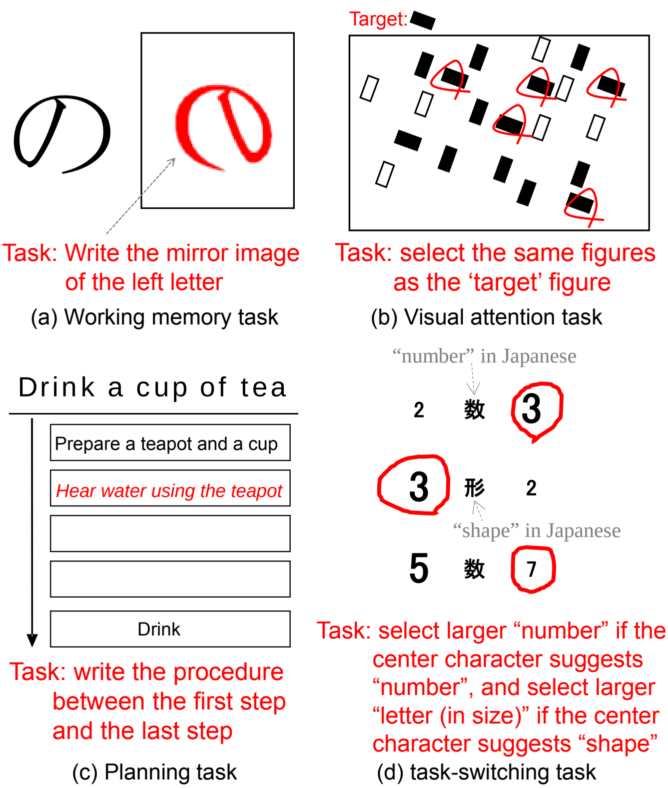

Fig. 1 Contents of AIST-CAT (Cognitive Aging Test)

2.3 Procedures: Questionnaire on self-awareness changes in cognitive and physical functions while driving

The questionnaire on self-awareness changes in cognitive and physical functions while driving is an assessment of consciousness about the changes in the information proceesing abilities (mainly, congnition, judgement, and execution) while driving [4]. The questionnaire consists of the following 7 factors: “changes in visual function”, “changes in precision driving operations”, “changes in ability to execute driving operations”, “changes in ability to assess traffic conditions”, “changes in ability to keep up with traffic flow”, “changes in workload sensitivity while driving”, and “changes in motion control function”. 4-point scale was used, indicating “no”, “somewhat I feel it”, “yes”, and “extremely I feel it”. Table 1 presents the contents of the seven factors.

Table 1: Questionnaire of the self-awareness changes in cognitive and physical functions while driving

Changes in Visual Functions
I now have difficulty seeing the arrows on traffic signals.
I now have difficulty recognizing the color of traffic signals.
I now have difficulty reading signs even during the day.
Changes in Precision Driving Operations
Backing into parking spaces has become difficult.
Parallel parking has become difficult.
Changes in Ability to Execute Driving Operations
Turning the steering wheel to turn at intersections has become reluctant.
I can no longer stop exactly where I want to at stop lines.
I can no longer maintain my concentration while driving.
Changes in Ability to Assess Traffic Conditions
While driving , the movements of surrounding vehicles now concern me.
While driving, the movements of motorcycles, bicycles and pedestrians are now annoying.
Overtaking forward vehicles now makes me nervous.
Changes in Ability to Keep up with Traffic Flow
I often find the distance between my car and the one in front has widened.
I now find that I more frequently step on the brake for every little thing while driving
I now have more difficulty driving with the flow of traffic.
Changes in Workload Sensitivity while Driving
I now get tired even when driving for only a short time.
I now get tired if the ride is not a smooth one.
Changes in Motion Control Function
Getting in and out of the automobile now takes some effort.

2.4 Procedures: Questionnaire on compensatory strategies

The questionnaire on compensatory strategies is a subjective assessment of the willingness for avoiding the following factors: “dual task while driving”, “driving in bad conditions”, “distraction due to passengers”, “tracing route with high workload”, “information acquisition from the road environment”, and “interaction with other road users”, and the intention of “relying on traffic rules” [5]. The rating scale is: 1 (No, statement does not describe my own driving); 2 (Occasionally, statement describes my own driving in some cases); or 3 (Yes, statement describes my own driving). Table 2 presents the contents of the 7 factors of the compensatory strategies.

Table 2: Questionnaire on compensatory strategies

Avoiding Dual Task while Driving
Turn off mobile phone while driving
Don't think about anything else and concentrate on driving operations while driving
Don't operate the audio equipment while moving
Avoiding Driving in Bad Conditions
Never drive when the field of view is bad due to bad weather, including rain or fog
Never drive at night because of difficulty in glancing at surrounding areas
Never drive on a slippy road due to a heavy rain or snow
Avoiding Distraction due to Passengers
Don't drive with another person because talking with him/her may distract you
Don't drive with another person because you can't take responsibility for traffic accidents
Don't talk with passengers because this may distract you
Avoiding Tracing Route with High Workload
Select a route with many wide roads
Select a route with many familiar roads
Avoiding Information Acquisition from Road Environment
Select a route with fewer traffic signals, because you will arrive at the destination earlier
When you lose your way, re-route based on your experience about surrounding areas, not based on traffic signs
Avoiding Interaction with Other Vehicles
When turning left, approach the left side in your lane in order to avoid a motorcycle that comes up on your inside
Activate a turn signal earlier to suggest one's drivingaction to other vehicles
Relying on Traffic Rules
Keep in mind watching traffic signs as frequently as possible

3 RESULTS AND DISCUSSION

It is difficult and inefficient to check separately whether each factor of the three sessions influences the other factors, because the number of the combinations between the 4 factors of cognitive abilities, the 7 factors of self-awarenesses, and the 7 factors of compensatory strategies is huge. We applied a Bayesian network model [6] to the measured data sets in order to investigate the relationships between the cognitive functions, the self-awarenesses of functional declines, and the compensatory strategies automatically and comprehensively.

Figure 2 suggests the prior knowledge before the model construction. It is hypothesized that the cognitive fuctions are the basic capability and the changes of the cognitive functions affest the driver's self-awareness. The willingness of taking compensatory strategies would be determined based on the cognitive functional declines and/or the self-awareness of the functional changes. The correlations among factors within each test were permitted.

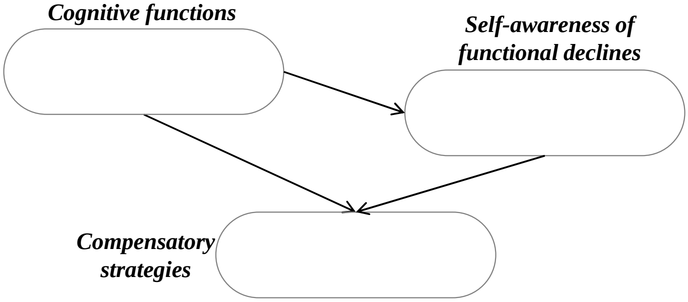

Fig. 2 Prior knowledge of Bayesian network model

Figure 3 presents the result obtained from the Bayesian network model. The self-awarenesses of "changes in ability to assess traffic conditions", "changes in ability to keep up with traffic flow", "changes in workload sensitivity while driving", and "changes in motion control function" were not related to the factors of the AIST-CAT and the questionnaire on compensatory strategies. The compensatory behaviors of "avoiding dual task while driving" and "avoiding distraction due to passengers" also had no relations to the items of the other tests.

"Visual attention" of the cognitive functions influences directly "changes in ability to execute driving operations", and the "planning" influences directly "relying on traffic rules". The self-awareness of the declines of executing driving operations and of controlling the vehicle precisously affects avoiding acquiring information from the road environment and avoiding driving in bad conditions, respectively. The understandings of executive performance declines contribute to elderly drivers' intention of driving under lower task demands.

The decrease of the visual attention is related to elderly drivers' awarenesses of the driving ability declines. This cognitive function has no direct influences on the compensatory driving behaviors. On the other hand, the decrease of the planning ability leads to elderly drivers' dependence on the traffic rules. The cognitive function of "planning" has direct influences on the compensatory strategies and no direct influences on the elderly drivers' awarenesses of the cognitive functions. These findings imply that it is difficult for elderly drivers to be aware of the decline of the planning function. The elderly drivers often feel the deterioration of visual attention in their daily activities, and they are aware of the declines in the pedal and steering operations.

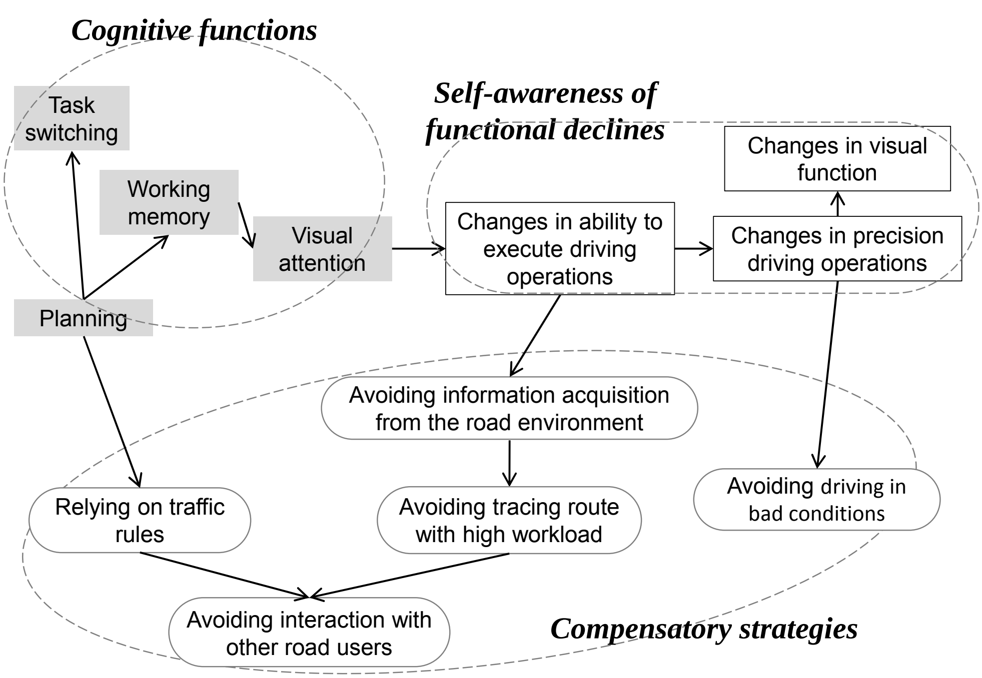

Fig. 3 Bayesian network model obtained from the measured data

4 CONCLUSIONS

We measured cognitive functions, consciousness of cognitive and physical functional declines, and driving strategies adaptive to the functional declines of 100 elderly drivers. The visual attention affects the elderly drivers' consciousness of the declines of vehicle control abilities. The planning function leads to taking the rule-based driving behaviors, and this function has no relations to the self-awareness of the functional changes.

5 ACKNOWLEDGMENTS

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EFFECTS OF AIRPORT ROAD ACCESS WAYFINDING ON SENIOR DRIVER BEHAVIOUR AND SAFETY

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ABSTRACT: The purpose of this study was to investigate the impact of different wayfinding and signage provision on senior driving behaviour. A car driving simulator was used to model scenarios of differing wayfinding complexity and road design. Three scenario types were designed consisting of 3.8 miles of airport road (i.e. approximately 4 minutes driving to complete each scenario). Wayfinding complexity varied due to differing levels of road-side furniture such as signage and bollards. Experienced car drivers were asked to drive simulated routes. Forty drivers in the age ranges: 50 to 54, 55 to 59 and those aged over 60 were selected to perform the study. Participants drove for approximately 20 minutes to complete the simulated driving. The driver performance was compared between age groups. Results were analysed by Mean, Standard Deviation and ANOVA Test, and discussed with reference to the use of the driving simulator. The ANOVA results confirmed that there is a low impact between driving behaviour and road safety on airport road access wayfinding design.

KEYWORDS: Wayfinding, Signage, Driving Behaviour, Simulator

1 INTRODUCTION

Good wayfinding (including signage) is one of the important elements to ensure the network of roads designed and operated to enable safe access in airport areas. Airport road access wayfinding is an important activity for people throughout their lives as they navigate to and from places in the airport. Lynch (1960) explained that wayfinding is the progressive process by which people reach a destination successfully. Carpman and Grant (2002) stated that wayfinding helps people to identify their location, their next destination, and to choose the best route to the intended destination. Montello and Sas (2006) agreed that wayfinding occurs when people need to travel from one place to another on the intended route and direction without accident or delay to reach their destination successfully. Drivers, pedestrians, cyclists, motorists and bus passengers of all ages and abilities should be able to move safely (Harding et al., 2011). Navigation defines as a process or activity for maintaining the movement which involves adaptive displays as directional signs and accurately following the planning and route (Kray, Kortuem, & Krüger, 2005; A. May, Ross, & Osman, 2005). The navigational process involves a combination of traditional and modern wayfinding elements. These elements turn to effective wayfinding if up to date information is loaded sufficiently. Woollett and Maguire (2010) agreed that drivers (i.e. even an expert driver) are unable to memorise road layouts and environments in unfamiliar areas. Drivers have difficulties to recognise scenes among similar looking environments and are unable to make a quick decision before properly adapting to the environment. Streeter et al. (1985) agreed that several traditional navigation methods (e.g. paper maps, recorded vocal directions, customised route maps and a combination of the latter two) help drivers in their journey. Driving in an unfamiliar area has resulted in 50% fewer cases of unsuitable driving behaviour than those using conventional navigation methods (TNO, 2007). 2 The navigation system conveys route guidance to the driver using visual displays (such as traffic signs). Research has long found that the navigation will direct and produce the shortest routes (in terms of distance and time) to drivers, and result in the fewest navigational errors. Senior drivers may have difficulties in following the correct routes and find navigation particularly difficult due to degradation of their cognitive, perceptual and motor skills (Dingus, McGehee, Hulse, Jahns, & Manakkal, 1995; A. May et al., 2005). Burnett (2000) stated that the display of the navigation system affected the frequency of glances and increased the number of navigational errors. Bhise and Rockwell (1973) supported that the duration of glances towards road traffic signs were almost twice as long in low density traffic as were in high density. The traffic signs assist senior drivers to know where they actually are on the road, the layout of the environment and the location of their destination for their driving plans. In many cases, drivers have difficulties to follow the traffic signs system due to fewer obstacles (e.g. too concentrating on signage and focussing on road) which causes stress, delay and potentially risky road behaviour (e.g. late lane changes or attempting to read paper or screen maps) while driving (A. J. May, Ross, & Bayer, 2005). Underlying health conditions, and some types of medication taken to treat those problems, are common factors in accidents involving senior drivers. Indeed, a proportion of senior driver fatalities occur when a senior driver dies of natural causes while driving, and so their vehicle immediately crashes. Senior drivers are commonly involved in collisions at junctions (RoSPA, 2010), because of misjudging the speed or distance of other vehicles or failing to see a hazard (Devlin & McGillivray, 2016). They are likely to drive slowly and in some circumstances they probably stop driving completely, particularly when approaching junctions. Although this may appear to be safe behavioural adaptation, their speed reduction can occurs without consideration of traffic regulations. However, not all senior drivers do this, and there is little guidance for drivers about it. A major deterrent to selfregulation or stopping driving is the lack, or perceived lack, of viable alternatives to the car. There are several cognitive and physical conditions which affect the ability to drive safely and which, therefore, could act as indicators of increased risk. One important question is how best to test for these conditions, as it is crucial that interventions do not unfairly cause senior drivers to lose their licence. There is comprehensive guidance for medical practitioners on how to assess fitness to drive, and what measures they can take to help their patients who are, or are becoming, unfit to drive. Age-related conditions eventually mean that there is a point when senior drivers should give up driving for their own safety. Due to fragile health and physical condition of senior drivers, they are more likely to suffer injuries when an accident happens (Cuenen et al., 2016). In the five years of 2010 to 2014, 11,439 senior drivers and, in total, 15,910 senior people (i.e. combined drivers and passengers) were seriously injured or killed in crashes on Britain’s roads (Department for Transport, 2015a). A massive number of road accidents (i.e. including airport road access) involving senior drivers have also been reported at airport ground access involving slight, seriously injured and fatal accidents. Thus, the drivers (including senior drivers) are exposed to the risky driving on the roads every day and more likely to die on the roads (Hill & Starrs, 2011). Road crashes remain the leading cause of death amongst senior drivers (RoSPA, 2010). WHO (2011) reported that the number of people aged 65 and over is projected to grow from an estimated 524 million in 2010 to nearly 1.5 billion in 2050. Driving represents the most significant mode of transportation for senior drivers in terms of mode share and distance travelled (O'Hern & Oxley, 2015). With an increasing ageing population throughout much of the developed world combined with increasing life expectancies, it is necessary to understand travel behaviour, mobility and safety implications of active transport used (i.e. the private car) on airport road access (Budd, Ison, & Ryley, 2011; Chang, 2013; Tam, Lam, & Lo, 2008) by senior drivers. Understanding senior drivers' mobility and accessibility needs was crucial to ensure that a specific requirement of road access systems is fully provided (Alsnih & Hensher, 2003). The researcher believes that the output of this research will be significantly beneficial to airport management, road sign design professionals and airport users, including senior drivers, in the future. In 2014, 60 drivers (aged of 50 to 59 years) and 183 drivers (over the age of 60 years) were killed in road accidents, 744 and 1,461 of drivers were seriously and slightly injured in these age groups, respectively (Department for Transport, 2015a). 3 Reported statistics indicate that the risk of an accident increases after the age of 60 up to 70, and they are no more likely to cause a crash than to be the victim of another road user's mistake. However, drivers over 70 are more likely to be at fault when they crash. Senior drivers' behaviour and safety are connected to the driving abilities and willingness to take risks on the road. The contrast between the safety performances expected of road transport and the management of all other risks is stark, not least when compared with other transport modes (e.g. rail and sea) in terms of fatality and the total of all casualty categories (Department for Transport, 2015c; Evans, 2003; Gayle, 2014). Senior drivers felt that their driving experience skills and driving abilities may not be as good as they once were, which in turn, means that they started to have difficulties in assessing complex problems or high-speed traffic situations and required additional information process time to make a decision (Hassan, King, & Watt, 2015; IAM, 2010). Road safety plays a fundamental role by decreasing the risk of being involved in an accident. Engineering measures such as a road design can prevent accidents and injuries to senior road users (RoSPA, 2010). RoSPA suggested that due to a higher number of accidents at junctions were involving senior drivers, road planners should redesign areas in which high crash rates are reported. An important aspect of senior drivers' safety is being able to accurately identify which drivers are significantly more likely to be involved in crashes, and ultimately to help them give up driving and adapt to life without a car. Driving behaviour that led to risk of road accidents (i.e. failing to look properly, poor turn manoeuvre, speeding, aggressive driving, overtaking and tailgating the car in front, failing to stop for traffic lights, and unable to process information on signs) has appeared as a critical factor of distinguishing crashes involving senior drivers (Department for Transport, 2015c; Elander, West, & French, 1993; Godley, Triggs, & Fildes, 2004; Mårdh, 2016; Oltedal & Rundmo, 2006; RoSPA, 2010), which are caused by poor wayfinding on current road designs. Elander et al. (1993) claimed that the relationship between drivers' skills, behaviour and accident involvement is complex. Safe driving is clearly a complex skill in which various cognitive processes such as perception, attention and motor control are involved (Jamson & Merat, 2005). Elander, Jamson and Merat found that the association between drivers' skills and crash involvement were related through the changes in the way drivers are trained and tested. Driver education programmes that are specifically tailored to senior drivers are considered to have potential, although it can be hard to make sure the programme reaches the senior people. Exercise programmes help this group to maintain their health and their driving ability. A key question is how and when drivers should be relicensed? In the UK experience, this occurs at 70 years (and every three years thereafter) and requires only the driver to self-certify that they are fit to drive (DVLA, 2015). However, there is no research found that suggests a mandatory driving test would be effective to overcome incidents for senior drivers.

2 WHY SENIOR DRIVERS AND AIRPORT ROAD ACCESS

There are challenges in defining when an individual becomes an elderly or senior citizen. Most developed countries set the age of senior citizen at 65 years old, but in other regions such as Africa, the "senior" threshold is much lower at 50 years (WHO, 2016). Orimo et al. (2006) stated that with recent technology in the medical and health science industry, the average lifespan has increased rapidly, thus, such a definition of elderly to simply include all persons over 65 years might be no longer appropriate for this era with a life expectancy of 80 years. WHO (2016) agreed that a definition of senior is arbitrary and introduces additional problems of data comparability across nations. For example, the MDS Project collaborators agreed at the 200 Harare MDS Workshop to use the chronological age of 60 years as a guide for the working definition of “old”; however, this definition was revisited (i.e. “older” was set at the age of 50 years) due to it not taking into account the real situation of older persons in developing countries. Therefore, the airport road access wayfinding research set the minimum age of 50 years as a “senior”, and selected 40 senior drivers aged 50 years and above as a sample of the population. The definition 4 of “senior” being aged 50 years and above was set to allow an accepted minimum “older” age (i.e. based on the MDS Workshop case) globally (Kowal, Rao, & Mathers, 2003). This research, hopefully, could be extended to be applied to other countries for airport road access wayfinding improvements. We focus our research on the elderly population. This segment of the travel market is becoming increasingly important in many countries. Many airports report that the proportion of elderly passengers using their facilities has increased and is predicted to rise further in the years ahead. CrashMap (2015) reported the high road accidents rate on airport road access; i.e. London Heathrow Airport (LHR) had the highest reported casualties (129 casualties), followed by Gatwick Airport (43 casualties), Edinburgh Airport (39 casualties), Glasgow Airport (26 casualties), Manchester Airport (19 casualties) and London Luton Airport (15 casualties) in 2014. Senior drivers are likely to drive to the airport due to carrying extra luggage and preferring more time spent in the vehicle (Ashford, Mumayiz, & Wright, 2011; Chang, 2013). DfT (2015d) reported that private car is the preferred transportation mode to reach the airport; i.e. Manchester Airport (57 per cent), London Luton Airport (54 per cent), Gatwick Airport (43 per cent), Stansted Airport (39 per cent), and London Heathrow Airport (29 per cent). With a current ageing population throughout much of the developed world, there is an imminent need to understand the current transportation requirements (Alsnih & Hensher, 2003; O’Hern & Oxley, 2015) of senior drivers, and to ensure sustained safe mobility and comfort on airport road access (Chang, 2013; Chebli & Mahmassani, 2002;

O'Hern & Oxley, 2015). The results confirmed that the wayfinding has importance for the promotion of road safety. Hence, an improvement on airport road access wayfinding, road safety and comfort for senior drivers and airport users should be considered by airport management, road sign design professionals and road authorities.

3 METHODOLOGY

Driving scenarios were scripted within a general-purpose "world" provided by a simulator that included a dual carriageway, with buildings, static objects, pedestrian walk-ways and vegetation. Driving simulation is field experimentation using a model building technique to determine the effects of changes and computer-based simulations (Sekaran, 2003). It was developed to test drivers' performance on a virtual environment of airport road access wayfinding design. Drivers and architectural clues (e.g. signs, maps and buildings) were included in the driving wayfinding simulation (Raubal, 2001). A causal and effect analysis was performed with the control of the researcher in the experimental simulation (Beins & McCarthy, 2012; Sekaran, 2003) which validated selected research variables of the intended study. As stated by Raubal and Egenhofer (1998), the combination of drivers' choice (decision) and clues (i.e. sign message) in a real world can be measured through virtual simulation.

3.1 Scenario Specifics

The simulated driving was scripted using a Scenario Definition Language (SDL) provided by the STISIM Drive Software Version 2. The authoring software was used to add the necessary objects (e.g. direction and advertisement signs, bollards and pedestrians) and auditory cues which provided the driver with instructions (e.g. "That is the end of the simulation"). Scenarios were scripted within a general purpose of the simulator that was a mixture of dual carriageway, buildings, static objects, pedestrian pavement and vegetation. Three scenario types were designed to provide a variety of driving scenarios and complexity of the road designs to the airport. The complexity of wayfinding varied to assess the safe driving behaviour on alternative airport road access design. Drivers' decisions and judgement are extremely important while driving especially when they have to make a rapid decision or whilst making decisions under pressure at decision points (Casutt, Martin, Keller, & Jäncke, 2014; Hassan et al., 2015). Drivers need to demonstrate visual scanning of the driving environment. They also must be able to make a quick 5 scan of the signage information. Drivers often will face degrees of pressure and anxiety on journeys to airports in order to ensure that flights are not missed. We established three scenarios representing different degrees of airport road design complexity. Scenario 1 or 'Less Complex' scenario was designed to be as less busy as possible to test the effect of road design on drivers' wayfinding to the airport. Drivers' behaviour and safety during navigation were also tested. The signage placement and road furniture were included to assess drivers' adaption to the actual airport road design with accurate wayfinding (including signage) provided. Scenario 2 or 'Complex' scenario was designed as a busy road and more complex in terms of road access design and wayfinding (including signage). Curved roads and warning signage were included in order to measure the impact of airport road design on drivers' safety and driving behaviour. Multiple signage types (e.g. diamond and rectangle signs) in the simulation design were considered. Scenario 3 or 'More Complex' scenario was designed as a busiest airport road with different types of direction and warning signs (e.g. diamond and rectangle signs), advertisement signs and complexity of airport road design provided with accurate wayfinding systems (including signage). Advertisement signs are important to the airport as a revenue source and for airport identity or branding (Harding et al., 2011) and were considered in the simulation scenario. Different type of signs was considered in all three simulations. Hopkins et al. (1997) found that different type or form of signs are more effective than conventional signs and able to reduce accidents at crossing path and left turn movements (Hopkins et al., 1997). Additional road furniture such as street lights, bollards, bus stop, traffic lights, zebra crossings, pelican beacon, trees and buildings were included in the simulation design. Monitoring driving speed to assess driver behaviour is crucial (Chevalier et al., 2016). Godley et al. (2002) stated that driving at appropriate speeds on existing road conditions is related to driver's confidence. The driving speed is related to driving safety because rear-end collisions are more likely to occur when driving at low speeds. In addition, Shechtman et al. (2007) confirmed that a greater forward acceleration indicates variable speed during the turn; the more a driver slows down, the more would need to speed up again. They confirmed that driving at a variable speed through an intersection could potentially increase the possibility of rear-end collisions. As a result, several types of speed limit were used in the scenarios (e.g. 30 mph, 40 mph and national speed limit).

3.2 Procedure

The simulation participants were selected based on convenient sampling and participation in this study was completely voluntary. Convenience sampling is a non-random (nonprobability) sampling technique that involves using whatever participants can conveniently be studied. It is most often used during experiment-based research and is the best way of obtaining basic information in the most efficient way (Sekaran, 2003). Thus, convenient sampling is the most appropriate sampling design for this paper because the collection of information is collated from the population of participants who are conveniently available to provide it. 40 experienced car drivers holding a valid driving license volunteered to take part in the study. The age of drivers ranged from 50 to over 60 with a sample mean age of 58.60 years. Complete instructions were given before the simulation started. Drivers were instructed to drive to the airport with the aid of wayfinding and signage in the driving scenario. The simulation test was 3.8 miles long for each scenario and took approximately 20 - 30 minutes to complete all three simulations. Participants decided which route to use based on the provided signage and wayfinding systems. The scenario was tested randomly. Participants were not tested by order or number of simulation (i.e. for example, participant A was tested with scenario 1 followed with scenario 3 then scenario 2, participant B was tested with scenario 2 followed with scenario 3 then scenario 1, and participant C was tested with scenario 3 followed with scenario 1 then scenario 2).

3.3 Data Analysis

The mean and standard deviation were used in this research as they are the most common descriptive statistics, and a very useful tool of statistical rules, in normal distribution (Beins & McCarthy, 2012; Robson & McCartan, 2016; Sekaran, 2003). Beins and McCarthy (2012) stated that ANOVA compares group means to assess the reliability of different means. In this research, ANOVA was used to measure the most prevalent importance of driving behaviour, road safety and the complexity of road design. The ANOVA test measures the differences of the independent variable (e.g. drivers' age group) and the dependent variables (e.g. risk of collision and centreline crossings). The level of significance ($p < 0.05$) was set in this study while 95% confidence level was selected as a conventionally accepted level (Sekaran, 2003).

Table 1. Definition of driving errors in simulated driving

Term	Definition	Drivers' Mistakes (Variables)	Errors
Vehicle position	The anterior and posterior position of the vehicle in relation to other vehicles and/or objects and pavement markings	Tailgating	Inadequate space during merge or lane change, stopping too close or too far back from pavement markings and other vehicles
Lane maintenance (Knowledge and compliance to traffic regulations)	The lateral positioning of the vehicle during turns, straight driving, and lane changes. Reflects ability to maintain steering control and entering the road shoulder	Centreline crossing Road edge excursions	Drifting out of a driving lane, encroachments on perpendicular traffic, and/or wide turns
Speed regulation (Speed perception)	The ability to follow and maintain speed limits, having adequate control of acceleration and braking	Speed exceedances Traffic light tickets	Not stop completely at stop signs, traveling too slow/fast, inadequate merging speed, abrupt or inappropriate braking and acceleration
Adjustment to traffic signs (Compliance to traffic signs)	Ability to appropriately respond to driving situations including adjusting to traffic or pedestrian movements and changing road sign information, as well as recognising potential hazards	Speed exceedances	Not adjusting speed to the posted limits, choosing improper lane from posted signage, and improper response to traffic or pedestrian movement
Collision and accident	Off road accidents occurring when the driver steers the vehicle too far off the road and runs into another vehicle. It includes vehicles in either lane of traffic, cross traffic vehicles, and vehicles in the rear view mirror	Risk to collisions	When the driver collides with another vehicle, the pedestrian, or a vehicle approaching from the rear and displayed in the rear view mirror
Decision and judgement (Rapid decision and decision under pressure at decision point)	Demonstrating visual scanning of the driving environment and ability to quickly scan the signage information	Speed exceedances Risk to collisions	Not able to make a quick decision at decision point

Table 1 shows the definition of driving errors that were recorded by driving simulator. The types of errors during simulated driving that were documented; (1) risk of collisions, (2) exceeding the speed limit, (3) traffic light tickets, (4) centreline crossings, and (5) road edge excursions. Drivers' mistakes recorded the common driving behavioural errors made during the simulation run.

4 RESULTS

4.1 Hypotheses

Table 2 shows the mapping of research hypotheses, research variables and analysis techniques in the airport road access wayfinding research.

Table 2. Research Hypotheses, Research Variables and Analysis Technique

Hypotheses	Study Variables	Analysis Techniques
H_0. Low adverse impact of driving behaviour and road safety to complexity of airport road access design. **H_1: High adverse impact of driving behaviour and road safety to complexity of airport road access design.**	Factors that contribute to safe driving behaviour and road safety (IV) Airport road access wayfinding (DV)	**Frequency analysis (Mean and standard deviation)** **ANOVA Test**

4.2 Drivers' Age and Gender

There were a total of 40 respondents who volunteered to participate in this research as a convenience sampling design was applied. Table 3 shows the age group of senior drivers who volunteered as participants in this research.

Table 3. Range of drivers' ages

	Minimum	Maximum	Mean	Standard Deviation
Age	50	71	58.60	5.31

The minimum and maximum age of the senior drivers are 50 and 71 years old, respectively. Mean and standard deviation of age range was computed as 58.60 and 5.31, respectively. The mean and SD results revealed that most of the participants were aged in the range of 53 to 63 years.

In total, 24 male drivers (60 per cent) and 16 female drivers (40 per cent) successfully completed the driving simulation test. The selection of senior drivers' gender was based on convenience sampling and volunteered feedback during invitation timeframe (e.g. 6 months).

4.3 Key Factors Influence Senior Driving Behaviour

Figures 1, 2 and 3 show mean and standard deviation computed for senior drives' age mistakes based on 'Less Complex', 'Complex' and 'More Complex' road design, respectively. The results show that there is a low relationship between road design complexity and driving errors. The results also revealed that the road edge excursions was the most mistakes and 'disobeyed' red traffic lights was the lowest mistakes made by senior drivers in all simulated driving scenarios. Senior drivers preferred to drive near to the road edges (or road shoulders), 'too carefully' at the junctions and roundabouts 8 and surprisingly drove too fast in sections of the road that had lower speed limits. This pattern showed that senior drivers are less safe and are exposed to incidents on the road.

In the 'Less Complex' wayfinding design (Figure 1), senior drivers were likely to cross the road edge (mean=3.90, SD=2.32), be exposed to the risk of collisions due to driving too close to a vehicle in front (mean=1.43, SD=0.81), exceeding the speed limit (mean=0.33, SD=0.57), cross the centreline (mean=0.10, SD=0.30) and were less aware of red traffic lights (mean=0.05, SD=0.22).

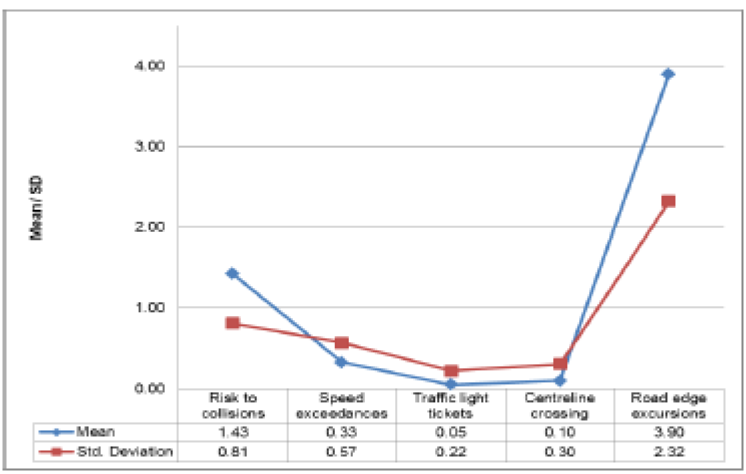

Figure 1. Mean and SD of drivers' age based on 'Less Complex' Scenario

Senior drivers' mistakes during the driving simulation test were recorded. In the ‘Complex’ wayfinding design (Figure 2), senior drivers were likely to speed and exceed the standard speed limit (mean=0.43, SD=0.84). They preferred to drive close to the kerb, which resulted in road edge excursions (mean=4.20, SD=4.44). However, they were likely to cross the centreline of the road lane (mean=0.15, SD=0.43) when attempting to turn at the next junctions. Tailgating as one of the major contributors to the road accidents could raise the risk of collision (mean=1.48, SD=0.91). Traffic light ticket (mean=0.03, SD=0.16) rates were low in the ‘Complex’ scenario, perhaps because of their experience from the “Less Complex” scenario test.

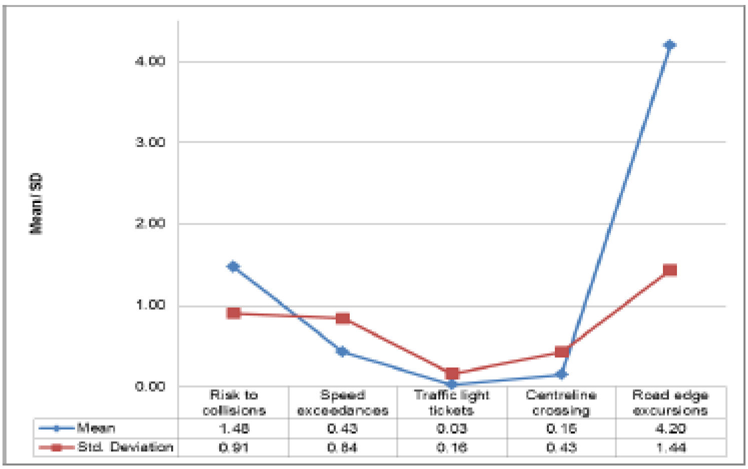

Figure 2. Mean and SD of drivers’ age based on ‘Complex’ Scenario

Drivers made more errors in the ‘More Complex’ wayfinding design (Figure 3); road edge excursions (mean=4.85, SD=1.12), risk to collisions (mean=1.63, SD=0.70), speeding (mean=0.60, SD=1.08), crossing the centreline (mean=0.35, SD=1.48), and less aware of red traffic lights (mean=0.13, SD=0.33) while performing navigation in this scenario. These five mistakes are the major factors influencing senior driving behaviour and safety on airport road access wayfinding design.

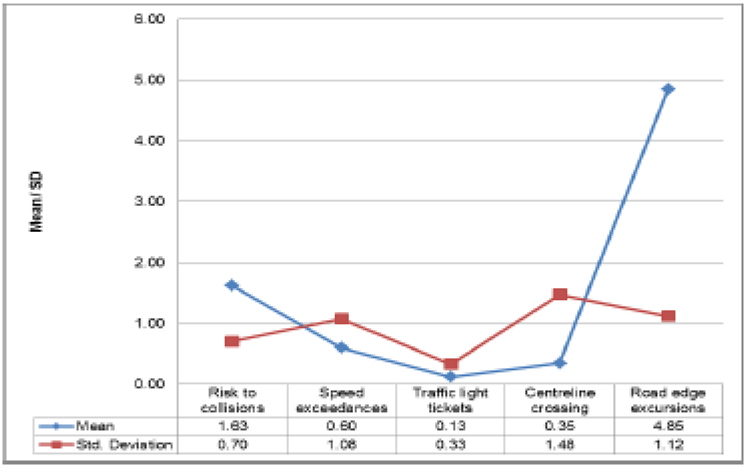

Figure 3. Mean and SD of drivers' age based on 'More Complex' Scenario

4.4 The Impacts of Driving Behaviour and Road Safety to Complexity of Airport Road Access Wayfinding Design

Table 4 shows the ANOVA test results of the research parameters.

Table 4. Summary of Senior Drivers' Mistakes in Simulated Driving

Driver's Mistake	Simulation 1		Simulation 2		Simulation 3	
	F	p-value	F	p-value	F	p-value
Risk to collisions	0.928	0.405	0.727	0.490	0.158	0.855
Speed exceedances	0.216	0.807	0.523	0.597	1.725	0.192
Traffic light tickets	0.849	0.436	1.177	0.319	0.720	0.493
Centreline crossing	0.742	0.483	0.146	0.865	0.826	0.446
Road edge excursions	0.564	0.574	1.262	0.295	1.228	0.305

The ANOVA result of risk to collisions shows that there was low statistically significant difference between risk of collisions and senior drivers' age group. It shows that senior drivers had no difficulties to reach the airport in Simulation 1 (F=0.93, p=0.41), Simulation 2 (F=0.73, p=0.49) and Simulation 3 (F=0.16, p=0.86). Therefore, there is low statistical impact to airport road access wayfinding designs on road safety. Based on Table 4, the highest possibility of senior drivers being exposed to a road accident was in the 'More Complex' (mean=1.63, SD= 0.70), followed by 'Complex' (mean=1.48, SD=0.91) and 'Less Complex' (mean=1.43, SD=0.81) scenarios. Senior drivers were observed to drive near to the road edges (especially at the roundabouts), had difficulties in making a fast decision at the decision point (e.g. junctions and approaching signs), and failed to respond to speed limit signs at low speed limit roads. These factors were contributory factors that lead to road collisions.

The ANOVA result shows low significant difference between speed exceedances and age group of senior drivers; Simulation 1 (F=0.22, p=0.81), Simulation 2 (F=0.52, p=0.60), and Simulation 3 (F=1.73, p=0.19). The results in Table 4 revealed that airport road access wayfinding design has low link to senior driving behaviour and safety. Drivers preferred to speed in the 'More Complex' (mean=0.60, SD=1.08) airport road access wayfinding design compared to the other scenarios. Variable speed limit signs were considered in the "More Complex" scenario; however, the results confirmed that the complexity of the airport road access wayfinding design less affect senior drivers' behaviour. Surprisingly, research results revealed that the speeding was controllable in the 'Less Complex' scenario (mean=0.33, SD=0.57). The 'less busy' and 'cosy' environment led senior drivers to the comfort driving without thinking of other tasks. Observation confirmed that senior drivers felt it to be comfortable and easy to navigate to the airport. DfT (2015c) reported that exceeding the speed limit and driving too fast are contributory factors to the accidents and casualties statistics. Exceeding the speed limit was reported in around 16 per cent of fatal accidents in 2014, whereas 8 per cent of fatal accidents were caused by driving too fast. A similar pattern was seen for reported road fatalities where exceeding the speed limit contributed to 17 per cent of fatalities and driving too fast contributed to 8 per cent of fatalities. The road statistics also revealed that 7 per cent of serious accidents and seriously injured casualties were allocated to the categories of exceeding the speed limit and travelling too fast.

The ANOVA result shows the airport road access wayfinding design has low significant effect on driving behaviour and road safety in terms of traffic light awareness. Senior drivers were less aware of red traffic lights in all scenarios; Simulation 1 (F=0.85, p=0.44), Simulation 2 (F=1.18, p=0.32) and Simulation 3 (F=0.72, p=0.49). Statistical results revealed that senior drivers are more likely to fail to stop at red traffic lights in the 'More Complex' scenario (mean=0.13, SD=0.33) compared to the 'Complex' (mean=0.03, SD=0.16) and ‘Less Complex’ (mean=0.05, SD=0.22) scenarios.

The ANOVA result shows the senior drivers’ age had low effect on road centreline crossing in all scenarios. Drivers are likely to cross the centreline more often in the ‘More Complex’ road design (F=0.83, p=0.45) compared to the ‘Less Complex’ and ‘Complex’ roads designs (F=0.74, p=0.48; F=0.15, p=0.87), respectively. The ANOVA results revealed that the complexity of road design affected senior driving behaviour. The complexity of the ‘More Complex’ scenario led senior drivers to cross road centrelines more often (mean=0.35, SD=1.48) compared to the ‘Less Complex’ (mean=0.10, SD=0.30) and ‘Complex’ (mean=0.15, SD=0.43) ones. Poor turn manoeuvre at roundabouts and junctions were main factors of unsafe driving behaviour. DfT (2015b) confirmed that poor turn manoeuvre led drivers to road accidents.

Table 4 shows there is a low significant effect between the senior drivers’ age group and road edge excursions; Simulation 1 (F=0.56, p=0.57), Simulation 2 (F=1.26, p=0.30), and Simulation 3 (F=1.23, p=0.31). The ANOVA test revealed that senior drivers crossed the road edge more frequently in the ‘More Complex’ scenario (mean=4.85, SD=1.12) compared with the ‘Less Complex’ (mean=3.90, SD=2.32) and ‘Complex’ (mean=4.20, SD=1.44) scenarios. As similar to centreline crossings, poor turn manoeuvre affected senior drivers’ safety which could lead to the risk of collisions. Senior drivers being likely to drive close to the kerb (e.g. to get a close view of traffic signs’ information) was the reason for the highest mean value.

Based on Table 4, the alternative hypothesis has been rejected and at the same time the null hypothesis was accepted at a significant alpha of 0.05. The hypothesis states that there is a low impact between driving behaviour, and road safety on airport road access wayfinding design.

5 DISCUSSION AND CONCLUSION

The paper suggests that driving simulation is useful for testing drivers’ wayfinding ability in a virtual environment. The study investigated the impact of different wayfinding and signage provisions on driving behaviour in three groups aged 50 and over. ANOVA results showed that drivers’ particular age group had a low impact between driving behaviour and road safety on airport road access wayfinding design. There are several contributory factors that may influence safe driving behaviour. 11

In order to emphasize the driving simulation results, the preferred key factors leading to road accidents have been considered as shown in Table 5.

Table 5. Mapping of contributory factors influence safe driving behaviour

Contributory Factors	Risk to collisions	Speed exceedances	Traffic light tickets	Centreline crossings	Road edge excursions
Failed to look properly	X	X	X	X	X
Poor turn or manoeuvre	X			X	X
Failed to judge other drivers' path or speed	X	X			
Following too close	X				
Disobeyed 'Give Way' or 'Stop' sign or markings	X	X	X	X	X
Loss of control	X			X	X
Travelling too fast	X	X	X	X	X
Swerved	X			X	X
Exceeding speed limit	X	X	X		
Aggressive driving	X	X	X	X	X

DfT (2015c) reported that road accidents involving fatalities of senior drivers have only fallen by 15 per cent from the years 2005 to 2009. However, road accidents that involved serious injuries rose 10 per cent over the same period. DfT reported that in the year 2000, people aged 60 or over accounted for about 20.8 per cent of Great Britain's population. By 2013, this had risen to 23 per cent, just over a 10 per cent increase. As the number of people in the senior age group increases, a higher number of road accidents involving senior drivers would be expected. In addition, as people get older their health condition becomes more infirm (Cuenen et al., 2016; WHO, 2011). Thus, it could lead to problems such as poorer depth perception and an increase in mistakes in both cognitive and physical behaviour (Department for Transport, 2015c; Marin-Lamellet & Haustein, 2015; RoSPA, 2010; WHO, 2011). These factors affected senior drivers' ability to focus on the road while driving to the airport.

There are three major of driving simulation that affects the ease of driving orientation and wayfinding designs to the airport. Firstly, the sign design of driving scenario's should be distinctive and different (Harding et al., 2011).

Airport ‘directional arrow’ sign should be bigger, bold text, different colour and symbol than other signs. The airport landside signs should be identical in term of size, colour and style to be compared with current motorway signs. The senior drivers could differentiate and signifies the airport signs while they are performing wayfinding. Therefore, it is very important that airport signs adhere to copy, styles and sizes, consistent terminology and symbols and uniform colours of basic guiding principles standard functions (AASHTO, 2010; Harding et al., 2011; Smiley, Houghton, & Philp, 2004). Message content should be easily understood by airport travellers. For instance, first time travellers require different information rather than frequent flyers. Secondly, some attributes in driving simulation can be seen from various viewpoints. For example, the ‘Less Complex’ scenario was developed with ‘comfort’ driving environment which allows drivers to view the routes and landmarks more easily and distinctively compared than other scenarios. Adding more to that, in some attributes of simulated driving such as ‘More Complex’ scenario, senior drivers require sign direction to be displayed as far as possible to the airport (AASHTO, 2010). Thirdly, as age increases, it is certain that general health and fitness will begin to deteriorate which leads to road accident risks. The senior drivers felt that their driving experience skills and driving abilities may not be as good as they once were (RoSPA, 2010). As a result, senior driver control their driving experience and develop a more defensive and cautious driving behaviour as they grow older. The senior drivers are commonly involved in collisions often because they misjudge the speed or distance of other vehicles or fail to see a hazard (Cuenen et al., 2016; Devlin & McGillivray, 2016; WHO, 2011). From the driving simulation results, it shows that the ‘more complex’ of road design makes wayfinding more difficult. For instance, the senior drivers made more errors in the ’more complex’ scenario which led to risk of collisions, exceeding the speed limit, centreline crossings, and road edge excursions. Senior drivers are more likely to have more driving errors which leads to road accidents.

In conclusion, the study revealed that senior drivers’ attention and ability to process signage and wayfinding information is limited. These limitations can create difficulties because driving requires the division of attention between control tasks, guidance tasks and navigational tasks. Drivers’ attention can be switched rapidly from one wayfinding information source to another. This means that drivers only attend well to one source at a time. For instance, while driving to the airport, drivers can only extract a small proportion of the available information from the road scene (i.e. airport directional signs). Thus, to interpret a limited information processing capacity while driving, drivers can only determine acceptable information loads that they can manage (Mårdh, 2016). When drivers' acceptable incoming information load is exceeded, they tend to neglect other information based on level of importance (i.e. if driver was looking for the word 'airport' on the sign, they tend to neglect the speed limit signs). As with decision making of any sort, error is possible during this process (Casutt et al., 2014). Drivers were less focused on information that turns out to be important, while less important information was retained. In addition to information processing limitations, drivers' attention is not fully within their conscious control. For drivers with some degree of experience, driving is a highly automated task. Driving can be performed while the driver is engaged in thinking about other matters. Most drivers, especially a frequent traveller to the airport or one familiar with the airport route, have experienced the phenomenon of becoming aware that they have not been paying attention during the last few miles of driving (e.g. airport staff). The less demanding the driving task, the more likely it is that the drivers' attention to the airport wayfinding and signage will wander, either through internal preoccupation or through engaging in non-driving tasks. Factors such as complexity of road design and environment or increased traffic congestion could also contribute to distracted driver's ability to keep track of wayfinding. Inattention may result in unintentional movements out of the lane, exceeding the speed limit (Chevalier et al., 2016) and failure to detect a vehicle on a conflicting path at an intersection (Dukic & Broberg, 2012; Mårdh, 2016; Oxley, Fildes, Corben, & Langford, 2006) that exposed drivers to the risk of collisions and reduced road safety.

5.1 Limitations

Driving simulators have a few disadvantages. For instance, simulator sickness (a type of motion sickness) is experienced by senior drivers whilst "driving" in the simulator room; it may include dizziness, headache, nausea and vomiting (Mourant & Thattacherry, 2000). Apparently, a senior driver would be compromised when experiencing these symptoms and it may not be appropriate for all drivers to be involved in a simulated driving experience. Gruening et al. (1998) claimed that the information gained through driving simulations may be misleading if the simulator does not provide an appropriate analogue to the simulated scenario, and that high reliability driving simulations are sometimes far more expensive than vehicle testing.

5.2 Future Research

The use of a driving simulation to test driver perception, driving behaviour and road safety is expanding rapidly; simulation saves engineering time and costs (Kemeny & Panerai, 2003). Driving simulators have become an essential means to improve knowledge in the fields of driving behaviour and road safety. It allows investigations concerning in particular a driver's behaviour, vehicles conception and road infrastructures conception (Espié, Gauriat, & Duraz, 2005). This research addressed the gaps in the literature on the airport road access wayfinding and the relationship between senior driving behaviour and road safety on airport road access wayfinding design. A driving simulator has been used as a tool to measure the relationship between these variables. In this section, further directions for future research are suggested. Firstly, Satellite Navigation (Sat Nav) was suggested as one of the objectives to assess its impact on senior driving behaviour towards airport road access wayfinding. However, the Sat Nav was not built-in in the STISIM driving simulator Version 2. The idea of the insertion of Sat Nav as a tool to aid senior drivers to perform airport wayfinding hopefully would extend the current research, with additional variables on the impact of airport road access design using a simulated driving scenario. Secondly, senior drivers aged 50 years and over were chosen to participate in this research. Results from the simulated driving test were analysed and findings were measured only focusing on senior drivers attributes. It is suggested that this research could be extended to the younger drivers and with a consideration of gender to assess any effects on driving behaviour and road safety on the complexity of road design.

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