OCCUPANT INJURIES IN FRONTAL CRASHES BY AGE, WEIGHT AND BMI

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ABSTRACT

The paper used NASS/CDS to examine the distribution of belted front seat occupants exposed to frontal crashes and the resulting injured at the MAIS 3+ severity level. The data was subdivided by occupant weight, BMI, and age. Further subdivisions by gender and crash severity were included.

The age effect was most pronounced. Injury risk for all ages increases with delta-V. However, exposure at higher speeds is lower for occupants over 35 years old than for the younger population. Occupants under 35 experience the highest number of injuries in higher speed crashes while injuries to older occupants are more uniformly distributed. About 17% of the occupants with MAIS 3+ injuries were 55 and older and were also in low or moderate severity crashes.

The increasing weight and BMI of the US population was also evident in the data. Occupants weighing more than 205 lbs. in higher severity frontal crashes accounted for about 7% of the of the belted front seat occupants with MAIS 3+ injuries. Another 9.5% weighed between 175 and 205 lbs.

INTRODUCTION

Numerous studies have shown higher vulnerability to injury and death for older occupants involved in motor vehicle crashes [Augenstein, 2001; Fildes, 1991; and Mackay 1994, 2001]. Other studies of gender differences indicate that females, like older occupants, are more vulnerable to injury than males of the same age [Lenard 2001; Welsh, 2001]. Evans found that the same physical insult was three times more likely to fatally injure a 70 year old compared with a younger person age 15 to 45. He further showed that women age 15 to 45 were 25% more likely to be killed from a similar physical insult than their male counterparts [Evans 2001, 1991].

Studies of serious injuries by body region for restrained occupants in frontal crashes have shown that for belted occupants age 65+, the chest is the body region most frequently injured at the MAIS 3+ level [Augenstein, 2005]. Similar results were found for belted fatally injured older drivers in frontal crashes [Kent, 2005]. Earlier studies examined changes in chest injury propensity using cadaver testing and found a significant decrease in injury tolerance by age [Zhou, 2001].

Force limiting belts with low pay-out forces are one proposed countermeasure to reduce chest injuries to vulnerable older and female front seat occupants in frontal crashes [Augenstein, 2007, 2009; Digges, 2007]. A downside consequence of a belt with a low pay-out force is an increase in excursion. Unless properly designed, the excursion could become excessive in higher severity crashes. In addition, occupants in the higher weight range may also experience excessive pay-out in moderate and lower speed crashes.

Increases in the overweight and obese population have emerged as a major concern of US health professionals [DHHS, 2010]. Based on data from the National Health and Nutrition Examination Survey (NHANES) 2003–2006 and 2007–2008, more than two-thirds of adults in the United States are

overweight or obese, and over one-third are obese (http://win.niddk.nih.gov/statistics). A break-out of overweight individuals by gender is as follows: Women – 64.1%; Men 72.3%. A break-out of obese individuals by gender is as follows: Women – 35.5%; Men 32.2%. Further, 17% of Women and 11% of Men were severely obese. The percentage in the obese category has almost doubled during the past 40 years.

The Body Mass Index (BMI) is a metric to estimate the extent of human body fat, based on an individual's height and weight. To perform the calculation, the US Department of Health and Human Services (DHHS) uses the individual's body weight in kilograms divided by the square of his or her height in meters.

DHHS has assigned ranges to values of BMI as follows: (1) Less than 18.5 – underweight (2) 18.5 to 24.9 – normal weight (3) 24.9-29.9 overweight (4) 30 to 34.5 Obesity (6) 35+ Severe Obesity. (DHHS, 2010)

Recent evaluations of NASS CDS data identified that for a given stature, an obese occupant (BMI ≥30) has a 97% higher risk of fatality and 17% higher risk of MAIS3+ injury compared to occupants with a normal Body Mass Index (BMI) [Viano 2008]. A study by Mock et. al. (2002) similarly found that the risk of fatal injury increased 1.013 [95% CI: 1.007, 1.018] for each kilogram increase in body weight.

A purpose of the current study is to examine the populations of belted front seat occupants exposed to and injured in frontal crashes by weight, BMI, age, gender and crash severity. These variables are intended to provide insight into the populations with the lower injury tolerance that benefit from benign restraint systems. It will also provide insights into the size of the higher weight populations that may require additional safety technology to protect them in moderate and severe crashes.

METHODS

The National Highway Traffic Safety Administration (NHTSA) maintains the National Automotive Sampling System, Crashworthiness Data System (NASS/CDS) database of vehicle crashes in the United States. The NASS/CDS is a stratified sample of light vehicles involved in highway crashes that were reported by the police and involved sufficient damage that one vehicle was towed from the crash scene. Each NASS/CDS case contains a weighting factor that is used to extrapolate the individual cases to the national numbers. The distributions to follow are based on the NASS/CDS weighted events. The 2000-2009 NASS/CDS data was used to determine the distribution of belted front seat occupants exposed to frontal crashes and the resulting MAIS 3+ injuries. The analysis subdivided the population by occupant weight, Body Mass Index (BMI), gender and age. It also examined the distribution of weight and BMI by gender and crash severity. Crash severity, measured by deltaV, was partitioned into 3 categories as follows: 0-15 MPH, 15-25 MPH and 25+ MPH.

For the NASS data analysis, frontal crashes were defined as any crash where the principal direction of force (PDOF) was 1, 11, or 12 o'clock or the PDOF was 10 or 2 o'clock with the highest deformation location coded as front (F). Typically, crash severity is determined using the coded change in velocity or deltaV. These estimates are available for those cases where delta-V cannot be accurately computed during crash reconstruction. The NASS database provided 24,102 raw cases of belted front seat occupants exposed to frontal crashes. Of these occupants, 2,335 suffered MAIS 3+ injuries. When weighted, these cases expanded to 11,779,258 occupants with 175,486 MAIS 3+ injured. For analyses that required known delta-V the sample size was reduced by about 40%. In the analyses to follow, cases with unknown deltaV are included unless a separation by crash severity is required. Occupants younger than 9 years were excluded.

DISTRIBUTIONS OF OCCUPANT WEIGHT

Figure 1 shows the distribution of belted front seat occupants exposed to frontal crashes and the distribution of MAIS 3+ injuries. In this figure the data for both genders are combined.

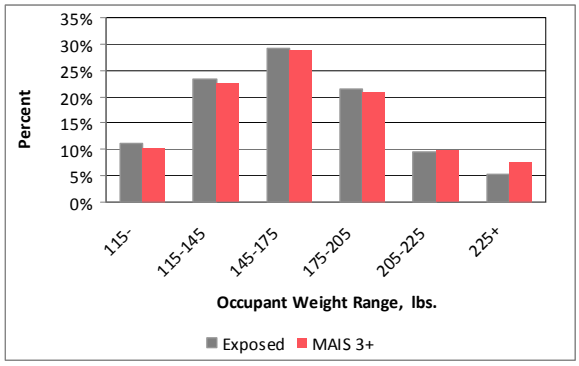

Figure 1. Exposure and MAIS 3+ injured by occupant weight for belted front seat occupants in frontal crashes

Figure 2 presents a break-out by gender of the MAIS 3+ injuries presented in Figure 1.

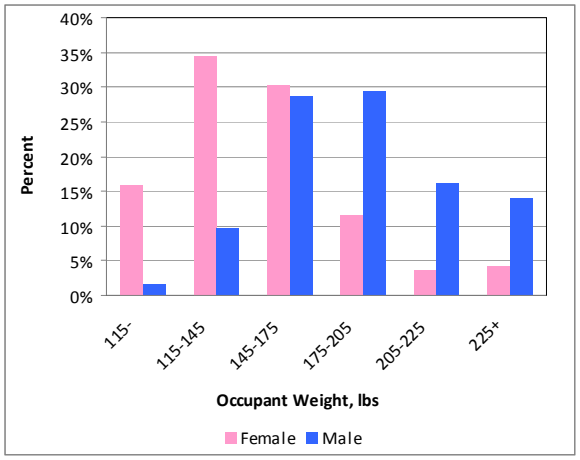

Figure 2. MAIS 3+ injured by occupant weight and gender for belted front seat occupants in frontal crashes

Figure 3 presents the rate of MAIS 3+ injured per 100 exposed to frontal crashes by occupant weight. The occupant weight is calculated as a 5 point moving average in order to provide some smoothing to the data.

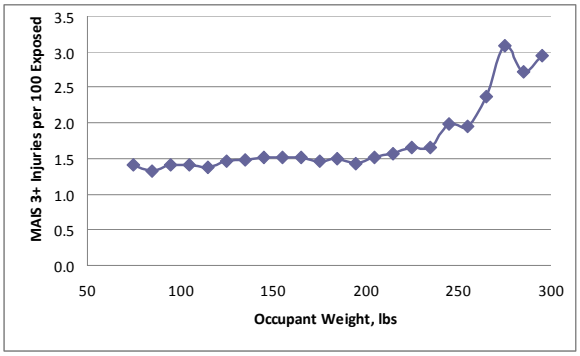

Figure 3. MAIS 3+ injured per 100 exposed by occupant weight for belted front seat occupants in frontal crashes

Figures 4 through 6 show the distribution of occupant weight by crash severity for the population with MAIS 3+ injuries. The crash severity is separated into three categories: (1) Low DV –less than 15 mph; (2) Mid DV – 15 to 25 mph and (3) Hi DV greater than 25 mph. The weight categories are as in the earlier figures. Figure 4 shows data for both genders, Figure 5 for females and Figure 6 for males.

Tables 1 through 3 display the data used to plot Figures 4 through 6. These tables also show the total distributions by weight and by crash severity.

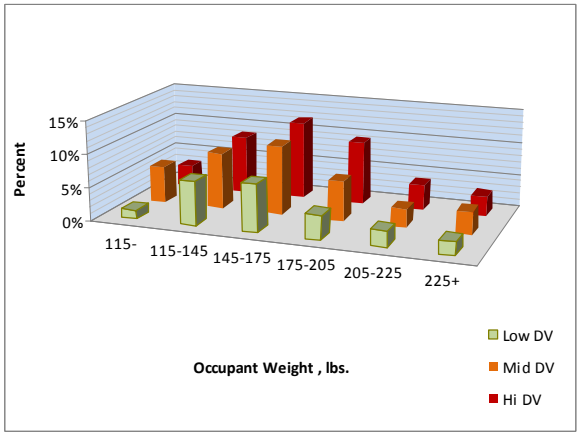

Figure 4. Both gender MAIS 3+ injured by occupant weight and crash severity for belted front seat occupants in frontal crashes

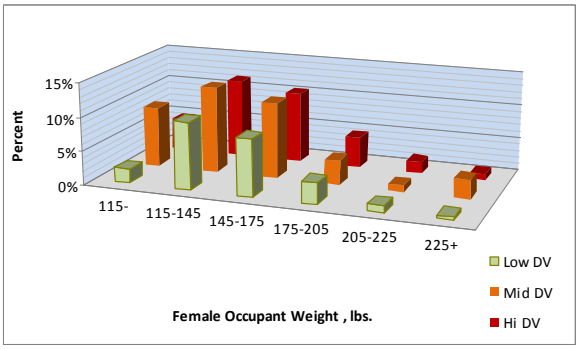

Figure 5. Female MAIS 3+ injured by occupant weight and crash severity for belted front seat occupants in frontal crashes

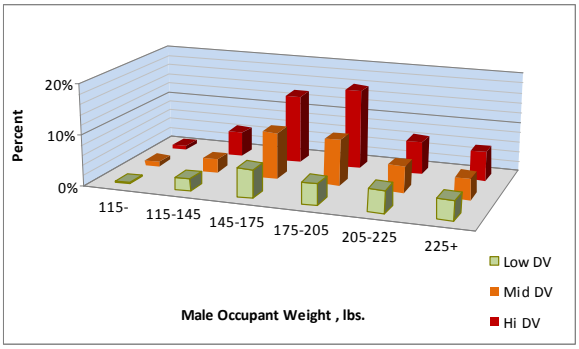

Figure 6. Male MAIS 3+ injured by occupant weight and crash severity for belted front seat occupants in frontal crashes

Tables 4 through 6 present the exposure data by occupant weight and crash severity. The crash severity categories are the same as for the MAIS 3+ injury data. Table 4 contains data for both genders combined. Table 5 contains female data and Table 6 contains male data.

Table 1.
Both gender MAIS 3+ injured by occupant weight and crash severity

Weight lbs.	Low DV	Mid DV	Hi DV	All
115-	1.4%	5.3%	3.0%	9.7%
115-145	6.7%	8.5%	8.7%	23.9%
145-175	7.2%	10.5%	11.9%	29.6%
175-205	3.7%	6.1%	9.6%	19.3%
205-225	2.4%	2.8%	3.9%	9.1%
225+	2.0%	3.4%	3.0%	8.4%
All	23.4%	36.6%	40.0%	100.0%

Table 2.
Female MAIS 3+ injured by occupant weight and crash severity

Weight lbs.	Low DV	Mid DV	Hi DV	All
115-	2.2%	9.0%	4.6%	15.8%
115-145	10.0%	12.8%	11.7%	34.5%
145-175	8.5%	11.3%	10.5%	30.3%
175-205	3.2%	3.7%	4.6%	11.5%
205-225	0.9%	1.0%	1.7%	3.6%
225+	0.5%	2.8%	0.9%	4.2%
All	25.3%	40.5%	34.1%	100.0%

Table 3.
Male MAIS 3+ injured by occupant weight and crash severity

Weight lbs.	Low DV	Mid DV	Hi DV	All
115-	0.3%	0.5%	0.8%	1.6%
115-145	2.4%	2.7%	4.8%	9.8%
145-175	5.6%	9.4%	13.7%	28.7%
175-205	4.3%	9.2%	16.0%	29.5%
205-225	4.4%	5.3%	6.7%	16.3%
225+	4.0%	4.2%	5.8%	14.0%
All	20.9%	31.3%	47.8%	100.0%

Table 4.
Both gender frontal crash exposure for belted front seat occupants in frontal crashes by occupant weight and crash severity

Weight lbs.	Low DV	Mid DV	Hi DV	All
115-	7.2%	1.5%	0.3%	9.0%
115-145	18.9%	5.1%	0.7%	24.7%
145-175	22.8%	7.0%	0.9%	30.8%
175-205	16.7%	3.9%	0.7%	21.3%
205-225	6.4%	1.9%	0.3%	8.6%
225+	3.9%	1.6%	0.2%	5.7%
All	75.8%	21.0%	3.2%	100.0%

Table 5.
Female gender frontal crash exposure for belted front seat occupants in frontal crashes by occupant weight and crash severity

Weight lbs.	Low DV	Mid DV	Hi DV	All
115-	12.8%	2.6%	0.6%	15.9%
115-145	29.4%	8.2%	1.1%	38.6%
145-175	19.0%	5.7%	0.8%	25.5%
175-205	9.1%	1.7%	0.3%	11.1%
205-225	2.8%	1.7%	0.1%	4.6%
225+	2.5%	1.7%	0.1%	4.2%
All	75.6%	21.5%	2.9%	100.0%

Table 6.
Male frontal crash exposure for belted front seat occupants in frontal crashes by occupant weight and crash severity

Weight lbs.	Low DV	Mid DV	Hi DV	All
115-	1.7%	0.4%	0.1%	2.2%
115-145	8.7%	2.1%	0.4%	11.2%
145-175	26.4%	8.3%	1.1%	35.8%
175-205	24.0%	6.0%	1.1%	31.2%
205-225	9.9%	2.1%	0.4%	12.5%
225+	5.2%	1.5%	0.4%	7.1%
All	76.1%	20.4%	3.5%	100.0%

DISTRIBUTIONS OF OCCUPANT BMI

In view of the increasing presence of overweight and obese individuals in the US, it is appropriate to examine the BMI population involved in motor vehicle crashes. In examining BMI, the DHHS categories were used with two exceptions. First, the severe obesity category was divided into two categories rather than one. Second, the underweight category was extended from 18.5 to 18.9.

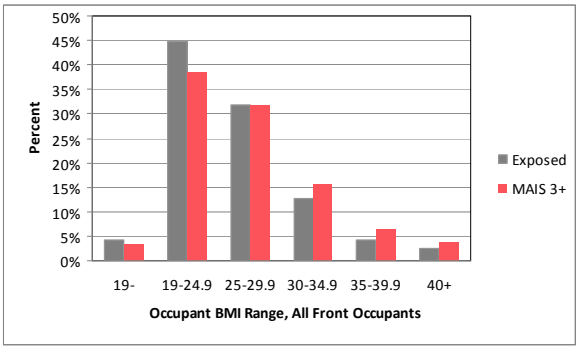

Figure 7. Exposure and MAIS 3+ injured by BMI for belted front seat occupants in frontal crashes

Figure 7 shows the distribution by BMI of belted front seat occupants exposed to frontal crashes and the

distribution of MAIS 3+ injuries. In this Figure, the data for both genders are combined.

Figure 8 presents a break-out by BMI and gender for the MAIS 3+ injuries presented in Figure 7.

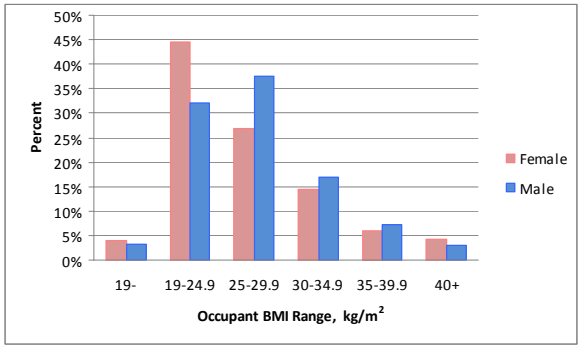

Figure 8. MAIS 3+ injured by occupant BMI and gender for front seat belted occupants in frontal crashes

Figure 9 presents the rate of MAIS 3+ injuries per 100 exposed to frontal crashes by occupant BMI. Both genders are combined in the figure.

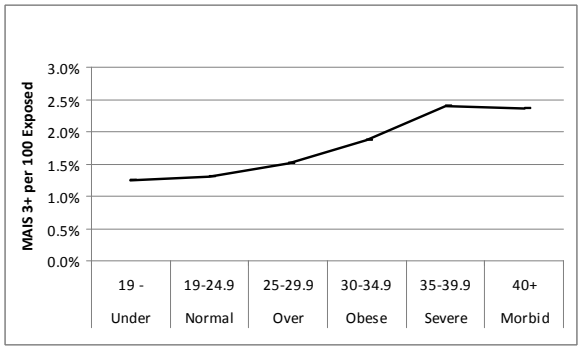

Figure 9. MAIS 3+ injured per 100 exposed by BMI for belted front seat occupants in frontal crashes

Figures 10 through 12 show the distribution of occupant BMI by crash severity for the population with MAIS 3+ injuries. The crash severity is separated into three categories: (1) Low DV –less than 15 mph; (2) Mid DV – 15 to 25 mph and (3) Hi DV greater than 25 mph. The BMI categories are as in the earlier figures. Figure 10 shows data for both genders, Figure 11 for females and Figure 12 for males. Tables 7 through 9 display the data used to plot Figures 10 through 12. These tables also show the total distributions by BMI and by crash severity.

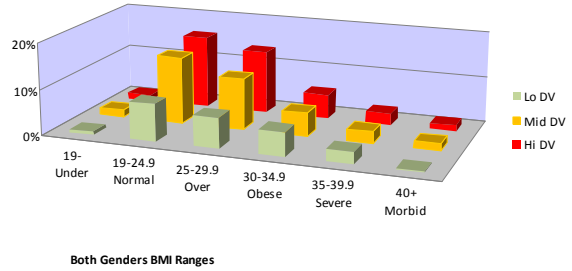

Figure 10. Both gender MAIS 3+ injured by occupant BMI and crash severity for belted front seat occupants in frontal crashes

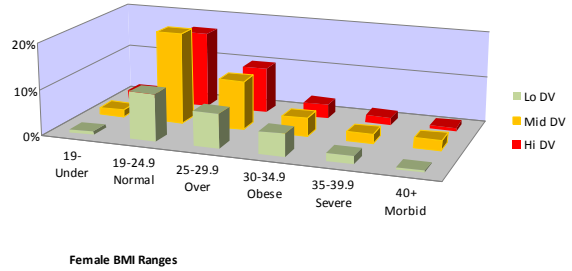

Figure 11. Female MAIS 3+ injured by occupant BMI and crash severity for belted front seat occupants in frontal crashes

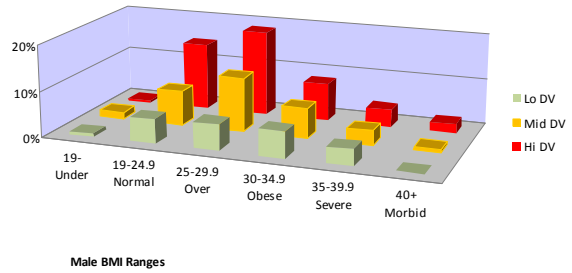

Figure 12. Male MAIS 3+ injured by occupant BMI and crash severity for belted front seat occupants in frontal crashes

Table 7.
Both gender MAIS 3+ injured by occupant BMI and crash severity

BMI	Range	Lo DV	Mid DV	Hi DV
Under	19-	0.7%	1.5%	1.2%
Normal	19-24.9	8.2%	14.7%	16.0%
Over	25-29.9	6.7%	11.1%	13.6%
Obese	30-34.9	5.2%	5.1%	5.4%
Severe	35-39.9	2.5%	2.6%	2.6%
Morbid	40+	0.2%	1.6%	1.3%
	All	23.5%	36.5%	40.0%

Table 8.
Female MAIS 3+ injured by occupant BMI and crash severity

BMI	Range	Lo DV	Mid DV	Hi DV
Under	19 -	0.7%	1.5%	1.7%
Normal	19-24.9	10.3%	20.0%	16.9%
Over	25-29.9	7.5%	10.6%	10.0%
Obese	30-34.9	4.8%	4.0%	3.1%
Severe	35-39.9	1.8%	2.1%	1.6%
Morbid	40+	0.3%	2.2%	0.8%
	All	25.3%	40.5%	34.2%

Table 9.
Male MAIS 3+ injured by occupant BMI and crash severity

BMI	Range	Lo DV	Mid DV	Hi DV
Under	<19	0.7%	1.3%	0.5%
Normal	19-24.9	5.4%	7.6%	14.8%
Over	25-29.9	5.7%	11.6%	18.4%
Obese	30-34.9	5.7%	6.6%	8.4%
Severe	35-39.9	3.5%	3.2%	3.8%
Morbid	40--49.9	0.1%	0.7%	2.0%
	All	21.1%	31.1%	47.8%

Tables 10 through 12 present the exposure data by occupant BMI and crash severity. The crash severity categories are the same as for the MAIS 3+ injury data.

Table 10.
Both gender frontal crash exposure for belted front seat occupants in frontal crashes by occupant BMI and crash severity

BMI	Range	Low DV	Mid DV	Hi DV
Under	<19	2.9%	0.6%	0.1%
Normal	19-24.9	34.6%	9.4%	1.3%
Over	25-29.9	24.1%	6.4%	1.1%
Obese	30-34.9	9.9%	2.4%	0.5%
Severe	35-39.9	3.2%	1.8%	0.1%
Morbid	40+	1.2%	0.4%	0.1%
	All	75.9%	21.0%	3.2%

Table 11.
Female gender frontal crash exposure for belted front seat occupants in frontal crashes by occupant BMI and crash severity

BMI	Range	Low DV	Mid DV	Hi DV
Under	19 -	5.0%	0.9%	0.3%
Normal	19-24.9	38.7%	10.5%	1.3%
Over	25-29.9	18.2%	4.8%	0.9%
Obese	30-34.9	8.3%	1.9%	0.2%
Severe	35-39.9	3.8%	2.9%	0.1%
Morbid	40+	1.7%	0.5%	0.1%
	All	75.6%	21.5%	2.8%

Table 12.
Male frontal crash exposure for belted front seat occupants in frontal crashes by occupant BMI and crash severity

BMI	Range	Low DV	Mid DV	Hi DV
Under	19 -	0.9%	0.4%	0.0%
Normal	19-24.9	30.7%	8.3%	1.3%
Over	25-29.9	29.7%	7.9%	1.2%
Obese	30-34.9	11.4%	2.8%	0.7%
Severe	35-39.9	2.6%	0.8%	0.1%
Morbid	40+	0.8%	0.3%	0.1%
	All	76.1%	20.4%	3.5%

DISTRIBUTION OF OCCUPANT AGE

All ages of front seat occupants in frontal crashes who were wearing lap and shoulder belts were included in the data query used to analyze occupant age. However, due to the small numbers of small children present the data was truncated at either age 10 or age 13.

Figure 13 is a plot of the percentages of occupants exposed to crashes and MAIS 3+ injured versus occupant age. Both genders were included. To smooth the data, a 7 point moving average was used.

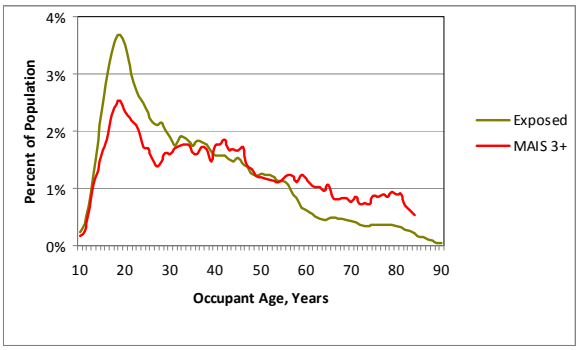

Figure 13. Exposure and MAIS 3+ injured by occupant age for belted front seat occupants in frontal crashes

Figure 14 presents the distribution by age groups of MAIS 3+ injured for male and female occupants.

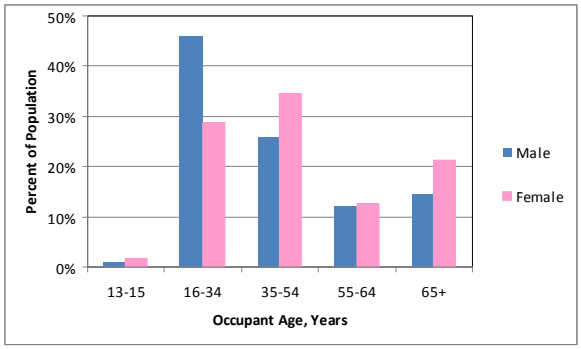

Figure 14. MAIS 3+ injured by occupant age and gender for belted front seat occupants in frontal crashes

Figure 15 shows the injury rate for male and female occupants versus age. The injury rate is in terms of MAIS 3+ injured per 100 exposed. The age data was smoothed using a 7 point moving average.

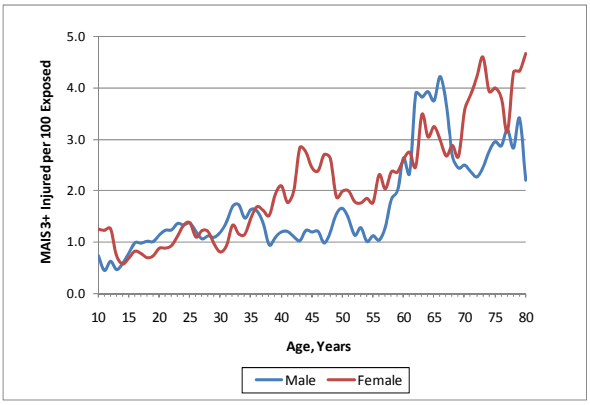

Figure 15. MAIS 3+ injured per 100 exposed by occupant age and gender for belted front seat occupants in frontal crashes

Figure 16 compares the crash exposure at the higher severity levels by occupant gender. The lower severity crash exposure was 74.9% for males and 75.6% for females.

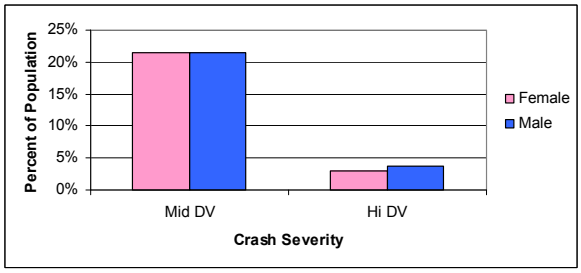

Figure 16. Occupant crash severity exposure and gender for belted front seat occupants in frontal crashes

Figure 17 shows the age at which the injured population is equally divided, with fractions rounded to the lower age. For each age shown, there are an equal number of older occupants with the same injury level.

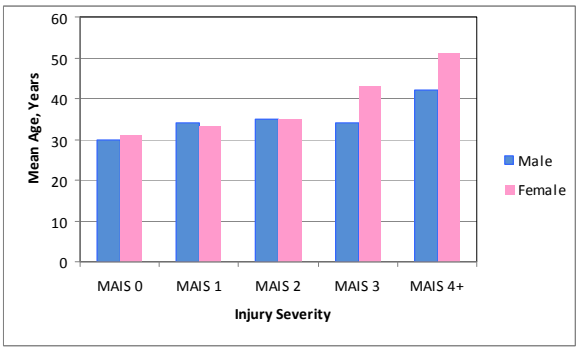

Figure 17. Mean age of population with each level of injury

Figure 18 shows the distribution of MAIS 3+ injured by occupant age and crash severity. The data for Figure 18 is presented in Table 13. Tables 14 and 15 break-out the Table 13 data by gender.

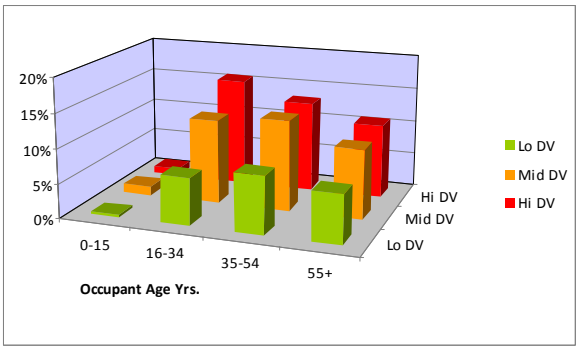

Figure 18. Both gender MAIS 3+ injured by occupant age and crash severity for belted front seat occupants in frontal crashes

Table 13.
Both gender MAIS 3+ injured by occupant age and crash severity

Age	Lo DV	Mid DV	Hi DV	All DV
0-15	0.4%	1.3%	1.0%	2.7%
16-34	6.8%	12.3%	15.8%	34.8%
35-54	8.3%	13.1%	13.2%	34.7%
55+	7.0%	10.0%	10.8%	27.8%
All Ages	22.5%	36.7%	40.8%	100.0%

Table 14.
Female MAIS 3+ injured by occupant age and crash severity

Age	Lo DV	Mid DV	Hi DV	All DV
0-15	0.2%	1.8%	1.2%	3.2%
16-34	5.9%	11.2%	10.6%	27.7%
35-54	10.9%	17.8%	12.3%	41.0%
55+	7.6%	9.7%	10.8%	28.1%
All Ages	24.6%	40.5%	34.9%	100.0%

Table 15.
Male MAIS 3+ injured by occupant age and crash severity

Age	Lo DV	Mid DV	Hi DV	All DV
0-15	0.7%	0.6%	0.7%	2.0%
16-34	8.0%	13.6%	22.4%	44.0%
35-54	5.0%	7.3%	14.3%	26.6%
55+	6.1%	10.4%	10.9%	27.5%
All Ages	19.9%	31.9%	48.3%	100.0%

DISCUSSION

The data presented provides insights into several current issues in motor vehicle safety. First, there is data to provide insights into questions regarding the degree to which current crash dummies represent the changing US population with regard to increasing weight and BMI. Second, it provides insight into the opportunities for addressing the needs of the older and female populations in frontal crashes. Third, it provides insights into the conflicting needs for low force belt systems for protection of the most vulnerable populations in low severity crashes and the higher force requirements in high severity crashes.

Hybrid III 5th percentile female dummy (50kg; 108lbs.) and the 50th percentile male dummy (77kg; 170lbs.) are currently used in regulatory crash tests to represent the population at risk. Figure 1 shows the distribution by weight of occupants exposed and injured. Figure 2 shows the weight distribution by occupant gender. The females are well represented by the existing dummies, although their largest population falls between the two sizes. However, about 60% of the MAIS 3+ injured males weigh more than 175 lbs, and 30% weigh more than 205 lbs. This heavier population will require a higher amount of energy absorption in a crash of equivalent severity and may not be adequately represented by the 50th percentile Hybrid III. Figure 3 indicates that the injury rate increases for occupants weighing more than 200 lbs.

Figures 4 through 6 and Tables 1 through 3 provide data on the weight distribution of occupants with MAIS 3+ injuries by crash severity and gender. The highlighted cells show the size of the heavier population in higher severity crashes with MAIS 3+ injuries. About 12.5% of the male population and 7% of the combined population injured at the MAIS 3+ level weigh 205 lbs. or more.

The BMI change in the population provides an additional complication for safety systems. Increasing BMI indicates an increase in body fat. Increases in body fat will influence the geometry of the safety belts and their loading of the body. The Hybrid dummies represent a physique with a BMI in the normal weight range. The Hybrid II 50% male dummy that was used in regulations beginning in the 1970's had a weight of 164 lbs and a BMI about 24. The current Hybrid III has an increased weight and BMI but not an increase in equivalent body fat.

Figures 10 through 12 and Tables 7 through 9 provide data on the BMI distribution of occupants with MAIS 3+ injuries by crash severity and gender. The highlighted cells in the tables show the size of the obese population in higher severity crashes with MAIS 3+ injuries. About 14.2% of the male population and 9.3% of the combined population injured at the MAIS 3+ level have a BMI of 30 or more.

A number of earlier studies listed in the Introduction section have shown the need for benign restraint systems for older occupants and for females. The Figures 13 through 18 and Tables through 15 display the age distributions and confirm these earlier findings.

Figure 13 shows the occupant exposure and MAIS 3+ injured as a function of age. The Figure shows that the population older than 55 is over represented in serious injuries. Based on Figure 15, young males between 16 and 34 are the group most frequently injured. However, Figure 13 shows that the younger occupants are also the most frequently exposed to higher severity crashes.

Figure 15 shows an increasing injury rate with age for both males and females. However, the data in this figure is not adjusted for crash severity. According to Figure 16, males are more frequently involved in the higher severity crashes. The difference in the crash exposure can be a strong factor that influences the total injury rate as reported in Figure 15.

Figure 17 shows that for both genders, age is a factor in the severity of the injury. As shown in this Figure,

the minimum age at which half of the injuries occur increases with injury severity.

The distribution of MAIS 3+ injured by age and crash severity is depicted in Figure 18. The data for Figure 18 is contained in Table 13. Tables 14 and 15 present similar data for females and males.

Belts with lower force limits in lower severity crashes are one possible safety feature to address these injuries. The injured population over 55 years of age and involved in moderate severity crashes constitute one of the populations that could benefit from more benign restraint systems. This population is about 10% for both males and females and it is highlighted in Tables 13 through 15.

CONCLUSIONS

The data presented in this paper is intended to assist safety researchers adapt to the changing US population as it becomes older and heavier. These two changes in the population tend to introduce conflicting requirements. The older population requires benign restraint systems. However, the heavier population may require more aggressive restraint systems in high speed crashes.

Based on NASS data about 10% of the belted front seat occupants with MAIS 3+ injuries in moderate severity frontal crashes are 55 or older. In total, about 35% of the MAIS 3+ population was exposed to moderate severity crashes, and another 22.5% were in low severity crashes. These populations would be the prime beneficiaries of benign restraint systems.

In contrast, about 7% of the of the belted front seat occupants with MAIS 3+ injuries in higher severity frontal crashes weigh in excess of 205 lbs. Another 9.5% weigh between 175 and 205 lbs. These populations present new challenges for restraint designers.

In crashes of all severity, about 60% of the belted male front seat occupants with MAIS 3+ injuries weighed more than 175 lbs. and 33% weighed more than 205 lbs.

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