AN NCAP STAR RATING SYSTEM FOR OLDER OCCUPANTS

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ABSTRACT

The objective of the paper was to apply to the NCAP star rating system injury risk functions that are more representative of the injury tolerance of older occupants. The NASS 1998-2008 data for front outboard occupants in NCAP like frontal crashes protected by air bags and safety belts was analyzed to determine injury risks by body region and occupant age groupings. The injury rates for NCAP like crashes were calculated for each applicable body region. Alternative injury risk functions were applied to 302 NCAP tests of vehicles model year 1988-2006. NCAP injury rates were calculated and compared with NASS data. The comparison was used to select injury risk functions to be applied to 2011 NCAP tests. Selected risk functions from the literature that produced injury rates in NCAP tests like those in NCAP like crashes were substituted for NCAP 2011 chest and neck injury risk functions. When applied to the 2011 NCAP tests there was a general downward shift in the star ratings awarded to the driver. However, the number of passengers with 5 star ratings more than doubled. For both drivers and passengers there were vehicles that advanced from 4 stars to 5 stars. The application of this alternative rating system would produce added incentives for safety designs that more correctly prioritize the reduction of injuries most harmful to older occupants.

INTRODUCTION

In the United States, the number of people of 65 years of age and older is expected to rise from 40.2 million in 2010 to 72.1 million in 2030, an increase of approximately 80 percent [US Census Bureau 2008]. Globally, the elderly population is increasing due to general declines in both fertility and mortality [United Nations 2009].

When exposed to frontal crashes, the injury risks for the elderly population differ from their younger counterparts in terms of both tolerance to injury and body region most susceptible to life threatening injuries. Numerous studies have shown that the chest region is much more vulnerable to life threatening injuries for the older population [Augenstein 2005, Kent 2005, Ridella 2012]. Age dependent injury tolerances for the chest have been proposed by several researchers [Zhou 1996, Laituri 2005, Prasad 2010]. The anticipated increase in the older population and their lower tolerance to crash injuries justifies the requirement for a vehicle rating system that is relevant to the safety needs of the elderly. The availability of accident data, crash test data and injury risk functions for elderly occupants permits the development of a methodology for a vehicle rating system tailored to elderly occupants.

The application of the Combined Probability of Injury index to NHTSA's 2011 NCAP program has significant merit from the standpoint of advancing the design and performance of vehicle safety systems. However, the index is based on the risks of injury to younger occupants. This paper applies risks that are more appropriate for older occupants to the recent NCAP frontal crash tests to determine how the star ratings would change. The objective is to provide a methodology for producing alternative NCAP ratings that could be used by older consumers. To develop such an alternative, it is necessary to answer research questions regarding how to develop and apply rating factors that prioritize the reduction of injuries suffered by older occupants so that the body regions most likely to be injured receive appropriate priority in the rating system. A related question seeks to determine how the star ratings of existing NCAP test vehicles would change when a rating system more appropriate for older occupants is applied to the test data.

Beginning with Model Year 2011, NHTSA introduced a wide variety of changes to the nature and structure of the NCAP rating program [Federal Register 2008]. The more significant changes, as they apply to the portion of the program involving frontal crash protection, included:

- Substituted a Hybrid III 5th percentile female dummy for the 50% male dummy in the front right seating position;
- Expanded the body regions monitored to include the neck;
- Substituted chest deflection in place of chest acceleration to assess chest injury risk;
- Substituted a 15 ms HIC in place of the 36 ms HIC to assess head injury risk;
- Selected injury risk functions that shifted the emphasis from AIS 4+ injury risk to AIS 3+ injury risk in the case of the head, neck and chest;
- Added AIS 2+ injury risk in the case of the knee-thigh-hip (KTH) complex; and
- Created and applied a combined injury risk (CPI) metric to calculate overall injury risk to the above-mentioned four body regions.

The combined injury risk (CPI) metric was defined as follows:

CPI= 1- (1-Phead)(1-Pneck)(1-Pchest)(1-Pkth)

Where:

Phead= Prob. of an AIS3+ Head Injury based on HIC

Pneck= Prob. of an AIS 3+ Neck Injury based on Nij or Axial Force

Pchest= Prob. of an AIS3+ Chest Injury based on Chest Deflection

Pkth= Prob. of an AIS2+ Knee-Thigh-Hip Injury based on Femur Loads

To support the changes, a new set of injury risk functions was defined for use in translating the dummy responses measured in the test into injury risk. These injury risk functions can be expected to influence both the restraint hardware and frontal structure in vehicles subject to test under the new rules.

The success of the New NCAP process hinges on the fidelity of the injury risk functions in predicting today's accident environment with the current demographics and the projected demographics ten to twenty years in the future. If the injury risk functions utilized in the rating scheme prioritize incorrectly, the resulting vehicles may not be responsive to the real-world safety needs of today or the future even for the highest rated vehicles.

The chest risk function for the New NCAP appears on page 40026 of the 2008 Federal Register Notice. When compared to age related risk curves developed by Laituri, the New NCAP curve corresponds to a 35 year old male [Laituri 2005].

Two examinations are necessary when considering the safety needs of older vehicle occupants. First, are the risk functions used for each body region representative of the injury tolerance of older occupants? Second, do the risk functions, when applied to the CPI and the resulting star rating, prioritize the body regions so as to optimize the restraint systems for older individuals? A purpose of this paper is to examine these two requirements in conjunction with the development of a rating system for older occupants. The suitability of an older occupant rating system for the NCAP test severity, its test procedures and the crash dummies employed are beyond the scope of this analysis. Earlier papers have indicated that a lower severity test would encourage better safety systems for older occupants [Digges 2007]. However, since test data at NCAP severity is available, the rating system will be applied to the 56 k/hr crash test data.

METHODOLOGY AND DATA SOURCES

In the sections to follow, the NASS data restricted to NCAP like crashes was used to determine the injury rates for each applicable body region and age grouping. Alternative injury risk functions from the literature were applied to 302 NCAP tests of vehicles model year 1988-2006. The resulting injury rates for the 302 NCAP vehicles were calculated and compared with the injury rates for NCAP like crashes in NASS. The comparison were used to select injury risk functions to be applied to 2011 NCAP tests. The selected risk functions from the literature were substituted for NCAP 2011 chest and neck injury risk functions and the changes in star ratings and injury priorities were determined. The approach was based on a research project conducted by D.J. Dalmotas Consulting, Inc. [Dalmotas 2011].

The 1988-2008 NASS data were searched for airbag equipped passenger vehicles that were involved in frontal collisions where at least one front outboard-seated adult occupant was restrained with a 3-point belt system. The study included impacts where the primary damage involved either the front of the vehicle or the primary damage involved the front left or right side of the vehicle forward of the passenger compartment and the direction of force was between 10 o'clock and 2 o'clock. Secondary impacts were permitted, but only if the damage extent number associated with the secondary side impact was less than CDC extent 3, indicating negligible interior compartment damage [SAE J224]. Rollovers were excluded.

The occupant sample was restricted to belted drivers and belted right front passengers who were seated in a position equipped with an airbag. Occupants restrained by a conventional, manual 3-point belt were included in the sample. Automatic seat belt systems, including door-mounted 3-point belt systems were excluded. As a minimum, the gender, age, and NASS MAIS rating had to be known.

For occupants with an MAIS rating between 0 and 2, the associated NASS collision weighting factor had to be less than 2,500. In the case of occupants with MAIS ≥ 3, the associated NASS collision weighting factor had to be less than 200. This was done to minimize distortions in the MAIS ≥ 3 injury frequencies which occur if filtering is confined only to collisions with very elevated NASS collision weights.

The above-mentioned selection criteria resulted in a frontal sample consisting of 19,907 front outboard occupants representing, when weighted, 6,109,236 occupants. The composition of the sample, in terms of vehicle damage assignments and Delta-V reporting are given in Table 1. Approximately 30% of the sample in Table 1 has unknown crash severity (delta-V).

Table 1.
Composition of Weighted and Unweighted NASS Belted Occupant Samples as a Function of Vehicle Damage

Primary Damage			Total Sample	
GAD	**SHA**	**PDOF**	**Weighted**	**Raw**
F	**C, D, L,R,Y,Z**	**Any**	5,684,747	18,746
L	**F**	**10, 02**	166,601	447
		11, 12, 01	73,664	212
R	**F**	**10, 02**	119,640	311
		11, 12, 01	64,583	191
All	**All**	**All**	6,109,236	19,907

The GAD in Table 1 is the direction of the General Area of Damage – Front, Left and Right. The SHA is the Specific Horizontal Area of the damage. The PDOF is the clock direction of the impact, as determined from the damage. These damage specifications are contained in the Collision Damage Classification (CDC) as defined in a standard from the Society of Automotive Engineers [SAE J224]. The six SHA designations for a frontal (F) GAD allow all crashes with frontal damage to be included in this classification. For the GAD left (L) and right (R), only damage to the front fender at the PDOF clock directions shown in the Table are included. These populations are considered frontal crashes.

The composition of the weighted occupant sample as a function of the occupant's "NCAP classification" and MAIS is depicted in Table 2. For the purposes of classifying occupants in the present study, an occupant was classified to have sustained an "NCAP" injury if he or she sustained one of the following:

- A head or facial injury rated as AIS 3+
- A neck or spine (any) injury rated as AIS 3+
- A chest injury rated as AIS 3+ or
- A lower extremity injury to the knee-thigh-hip complex rated as AIS 2+.

Of the 6,109,236 individual occupants represented in the weighted frontal sample, 109,523 of the occupants sustained at least one of the above-mentioned NCAP related injuries, yielding an overall occupant injury rate of 1.793% across all severities, independent of whether or not the Delta-V for the occupied vehicle was reported. Among occupants in the frontal sample rated as MAIS 4+, the percentage who sustained at least one NCAP injury was 97.5%. The only individuals excluded were those who sustained isolated injuries to the abdomen at the AIS 4+ level. In the case of occupants in the frontal sample rated as MAIS 3+, the percentage who sustained at least one NCAP related injury was reduced to 63.9%. The excluded occupants took the form of individuals whose AIS 3+ injuries were confined to the abdomen, to the upper extremities and to the lower extremities below the knee. The distribution of the individual injuries represented in frontal sample as a function of body region injured and the associated AIS severity level is provided in Table 3.

In Table 3, the 3+ injuries include AIS 3, 4, 5, and 6. These AIS classifications rank injuries with increasing severity from 3 (serious) to 6 (fatal). The AIS 7 classification specifies injuries with the extent unknown. AIS 7 injuries were not included in the 1&2 or 3+ categories but are included in the totals.

Table 2.
Composition of Weighted NASS Belted Occupant Sample as a Function of NCAP Classification and Maximum AIS Level

Injury Severity	Delta-V Unknown	Delta-V Known	% with NCAP Related Injuries
MAIS 0	965,091	2,010,176	0.00%
MAIS 1	650,174	2,104,713	0.00%
MAIS 2	58,563	250,364	19.40%
MAIS 3	16,433	39,895	63.90%
MAIS 4+	5,485	8,341	97.50%
All	1,695,747	4,413,489	1.79%

The distribution of all of the individual injuries in the "NCAP" occupant subset of the frontal occupants as a function of body region injured and associated AIS level is summarized in Table 4. In the Table AIS 7 injuries are included only in the "All" column.

The subset of the injuries in Table 4 which are NCAP-related are described in Table 5. Collectively we can see that the 109,523 (1.79% in Table 2) individuals designated as NCAP occupants in the weighted frontal subset sustained a total of 747,952 individual injuries, 173,024 of these being NCAP-related injuries.

Table 3.
Distribution of Individual Injuries Sustained by Occupants in the Frontal Sample as a Function of Body Region Injured and AIS Severity Level

Body Region	AIS 1&2	AIS 3+	All
Abdomen	409,422	6,970	421,263
Back	372,502	2,571	375,072
Chest	1,071,751	30,018	1,103,893
Face	1,203,236	1,744	1,205,031
Head	346,866	25,609	375,364
L Ext	2,037,155	46,628	2,084,322
Neck	767,939	4,552	772,855
U Ext	2,475,157	25,060	2,500,858
Unknown	35,414	41	35,542
Whole Body	1,291	0	1,291
All	8,720,733	143,193	8,875,491

Table 4.
Distribution of Individual Injuries Sustained by "NCAP" Occupants in the Frontal Sample as a Function of Body Region Injured and AIS Severity Level

Body Region	AIS 1&2	AIS 3+	All
Abdomen	35,529	4,866	40,497
Back	20,459	2,571	23,029
Chest	59,611	30,018	89,905
Face	68,935	1,744	70,679
Head	24,654	25,609	50,352
L Ext	268,867	38,652	307,519
Neck	21,183	4,552	25,909
U Ext	129,471	9,608	139,079
Unknown	874	41	915
Whole Body	68	0	68
All	629,651	117,661	747,952

Table 5.
Distribution of Individual "NCAP" Injuries Sustained by "NCAP" Occupants in the Frontal Sample as a Function of Body Region Injured and AIS Severity Level

Body Region	AIS 2	AIS 3	AIS 4+	All
Chest	0	18,645	11,373	30,018
Head-Face	0	15,522	11,832	27,354
KTH	78,602	29,517	411	108,530
Neck-Spine	0	5,938	1,184	7,122
All	78,602	69,623	24,800	173,024

In order to compare the priorities for protecting different body regions as related to occupant age, Table 6 was developed. The predominance of head and chest injuries is reflected in the distribution of individual AIS 4+ injuries as a function of the body region in the frontal occupant sample. Table 6 displays the relative ranking of the head and chest as related to the age of the occupant. Among younger occupants, those in the 15 – 43 years bracket, AIS 4+ head injuries can be seen to clearly predominate. In the case of the 44+ aged occupants, AIS 4+ chest injuries can be seen to predominate. The percentage of AIS 4+ injuries involving the neck-spine region among all three age groups was low, of the order of 4%.

Table 6.
Distribution of Individual AIS 4+ Injuries in Frontal Sample as a Function of NCAP Body Region and Age of Occupant

Occ. Age	Chest	Head-Face	KTH	Neck-Spine
15-43 Yrs	29.8%	55.8%	1.9%	4.2%
44-64 Yrs	**51.5%**	31.9%	1.4%	4.6%
65-97 Yrs	**51.2%**	37.1%	0.7%	4.1%
All	41.7%	43.4%	1.5%	4.3%

NASS DATA RESULTS

The objective of this analysis was to develop NASS data based injury rates by body regions for NCAP related injuries. The injury rates can be used to guide priorities for reducing injuries by body region and age groupings. Age groups and body regions with the higher injury rates suggest a higher priority for mitigation.

In order to assess the injury rates in field collisions at crash severities represented by the NCAP 56 km/h full frontal rigid barrier test, the NCAP injury data as described in Table 5 was used. Lower and upper bound injury rate estimates were computed from the NASS data using the Delta-V interval 49-64 km/h to provide the lower bound estimate and the Delta-V interval 56-71 km/h to provide the upper bound estimate. Table 7 shows the results. The lower bound injury rate estimate corresponds to 16.7%, while the upper bound estimate corresponds to 25.1%. A mid-point estimate of 20.9% was also listed

Table 7.
Injury Rate by Body Region: Any NCAP Injury / Bounded Estimates

	Field Data (NASS)		
Severity	49-64 km/h	56-71 km/h	M1d-point
Body Region	Lower Bound	Upper Bound	Mid-Bound
Neck-Spine	0.7%	0.7%	0.7%
Head-Face	2.4%	4.0%	3.2%
Chest	7.7%	13.6%	10.6%
KTH	11.3%	16.7%	14.0%
NCAP (Any)	16.7%	25.1%	20.9%

Table 8.
NCAP Injury Rates, All Crash Severities, as a Function of Occupant Age

Occupant Age Groups	Head-Face	Neck-Spine	Chest	KTH
	AIS 3+	AIS 3+	AIS 3+	AIS 2+
	MALE			
15-43 Yrs	0.15%	0.06%	0.23%	1.43%
44-64 Yrs	0.25%	0.12%	0.54%	1.51%
65-97 Yrs	0.33%	0.19%	1.09%	1.91%
All	0.19%	0.08%	0.37%	1.49%
	FEMALE			
15-43 Yrs	0.10%	0.03%	0.18%	1.27%
44-64 Yrs	0.33%	0.22%	0.64%	1.69%
65-97 Yrs	0.28%	0.38%	0.84%	1.44%
All	0.17%	0.10%	0.34%	1.38%

The variation in the NCAP body region injury rate for all crash severities as a function of occupant age is shown in Table 8. The greatest change is the increase in chest injury risk for the age 65+ male and female occupants – up by a factor greater than four when compared to the 15-43 age group. For the 65+ age groups of males and females, the AIS 3+ chest injury rate is at least three times the magnitude of the AIS 3+ head injury rates. The chest injury rates for 65+ men are at least 5 times higher than their neck injury rates. However, for 65+ women, their AIS 3+ chest injury rate exceeds the AIS 3+ neck injury rate by a factor greater than 2. These results suggest the need to increase the priority of protecting older occupants from chest injuries.

The change in chest injury risk with crash severity for the 65-97 year old group is displayed in Figure 1. Both weighted and unweighted NASS data are displayed in the Figure 1. The data was smoothed using an 11 point moving average. Both weighted and unweighted data show a sharp increase in injury risk at crash severities greater than 48kph. Figure 2 shows data similar to Figure 1 but for the population age 15 to 43. This is the population that is best represented by NCAP injury risk functions.

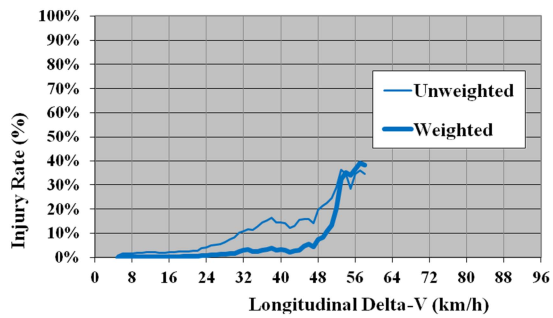

*Figure 1***.** Chest AIS >= 3 injury rate as a function of longitudinal delta-v front outboard occupants of light-duty passenger vehicles adults 65+ yrs / NASS: 1988-2008.

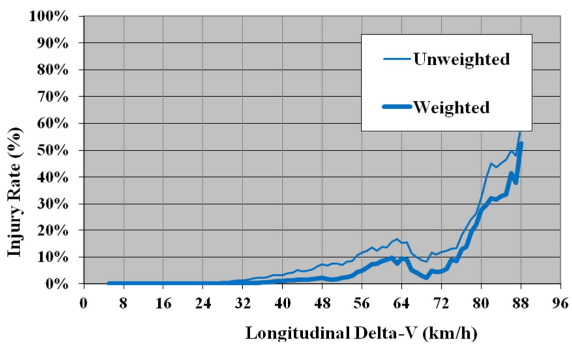

Figure 2. Chest AIS >= 3 injury rate as a function of longitudinal delta-v front outboard occupants of light-duty passenger vehicles adults 15 - 43 yrs NASS: 1988-2008**.**

ALTERNATIVE RISK FUNCTIONS

In selecting risk functions to be used in a rating system for older occupants, the relative magnitude of the injury rates presented in Tables 7 and 8 need to be used for guidance. Table 7 shows that, for the older population, the chest has the largest increase in injury rate. Consequently, chest injury risk curves that are representative of the older population should be employed.

In the case of the chest, NHTSA elected to employ an injury risk curve normalized to a 35 year-old occupant on the basis that this corresponds to the mean age of the U.S. driving population. As shown in Table 8 and Figures 1 and 2, the risk of chest injury varies greatly as a function of age. The injury rate of belted male and female occupants between 44 and 64 years of age is greater than twice that of occupants between 15 and 43 years of age. For the oldest segment of the population (65+) the increased risk is greater than 4. Of the chest injury risk curves already defined in the published literature, the "older male" proposed by Prasad et al. [2004, 2010] was selected to represent the older population with increased chest injury risk. Figure 3 displays the age related chest injury risk curves proposed by Prasad. [Prasad 2010]. The figure also shows the risk curve used by the 2011 NCAP rating system [Prasad 2010].

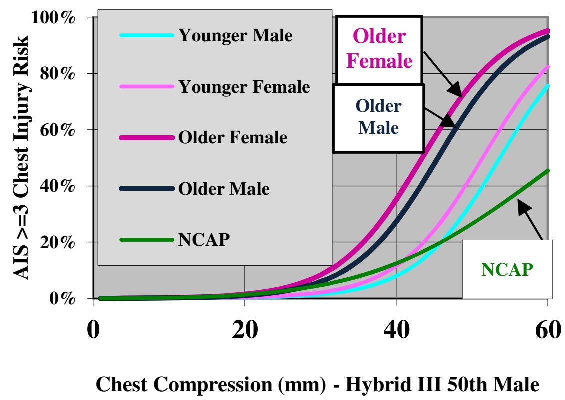

*Figure 3***.** Alternative chest deflection injury risk curves for 50% male Hybrid III dummy.

In the case of neck injury, the 2011 NCAP employed a risk curve that retained a residual risk of approximately 4% at zero value of Nij. The NCAP neck injury risk curve is displayed in Figure 4. Also shown in Figure 4 are neck injury risk curves with and without muscle tone suggested by Mertz [2003]. Table 5 indicates that the risk of neck/spine injury in NCAP like crashes is less than 1%. Consequently, the NCAP neck injury risk curve is expected to overstate the injury risk at lower values of Nij.

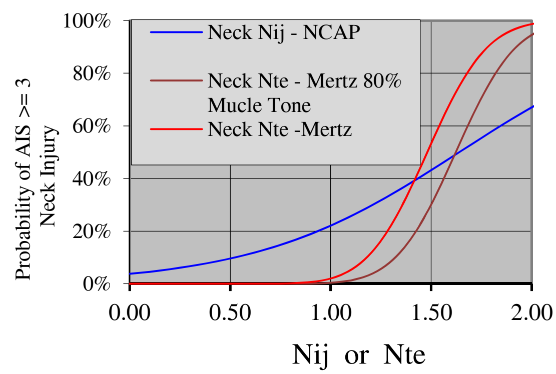

Figure 4. Alternatives Nij injury risk curves for 50% male Hybrid III dummy.

Another neck injury risk curve used by NHTSA is applied to out-of-position occupants exposed to air bag deployments. The neck tension and compression are used as injury measurements in these applications. Figure 5 shows this NHTSA neck tension/compression risk curve. Also shown in Figure 5 are neck injury risk curves with and without muscle tone, proposed by Mertz [2003].

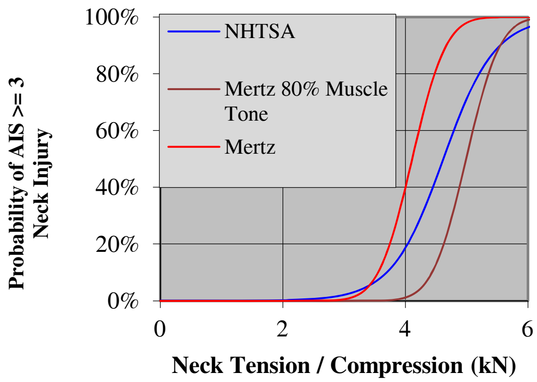

Figure **5.** Alternative neck tension/compression injury risk curves (N_{te}) for 50% male Hybrid III dummy.

INJURY RISK CALCULATIONS FOR NCAP VEHICLES MODEL YEAR 1988-2006

To explore how body region injury rankings generated by the injury risk functions used in NCAP correlate with field data, a retrospective review of NCAP tests previously performed by NHTSA was undertaken. Data for a total of 456 NCAP tests were secured and processed using the injury risk functions that are used in the 2011 NCAP program. This total included 302 tests of model year (MY) 1988 to 2006 passenger vehicles. This subset of tests was judged to most closely represent the vehicle population in the NASS database.

This group of 302 vehicles tested by NCAP was used to assess how well alternative risk functions predict the injury rates in NCAP type crashes. First, the 2011 NCAP injury curves were applied to the 302 vehicles and the mean injury rates for each body region were calculated. Second, alternative injury curves were applied to the same 302 vehicles. The results of the two calculations were compared with the injury rates observed in NASS field data for NCAP severity crashes. The results are shown in Table 9.

Table 9 displays the mid-estimate of injury risk that is representative of NCAP like crashes, based on NASS data. This mid-estimate was previously displayed in Table 7. The application of NCAP risk functions to the 302 NCAP vehicles that are representative of vehicles on-the-road is displayed in the third column of Table 9. The right column of Table 9 displays the injury rates when alternative risk functions were applied to the 302 NCAP vehicles. The alternative risk functions replaced the NCAP Nij risk with the Mertz N_{te} risk (neck with no muscle tone, Figure 5) and the NCAP chest risk function with the Prasad older male risk (Figure 3). Table 9 provides a comparison of actual injury risks in NCAP like crashes in NASS field data with calculated injury risks based on NCAP test data of 302 vehicles that are representative of vehicles on-the-road.

Table 9.
Comparison of Injury Risks Derived from NASS Field Data with Those Derived from NCAP tests (Driver Only)

Body Region	Field Data	NCAP Test Data	
	NASS Mid-Bound	NCAP 2011 Risk Functions	Elderly Risk Functions
Neck-Spine 3+	0.70%	7.90%	0.55%
Head-Face 3+	3.2%	2.3%	2.3%
Chest 3+	10.6%	6.8%	12.5%
KTH 2+	14.0%	4.9%	4.9%
NCAP (Any)	20.9%	20.1%	20.2%

DISCUSSION

A comparison of the injury probabilities the injury rates for the human driver derived from the NASS analyses and for the hybrid III driver derived from the series of 302 tests is presented in the center two columns of Table 9. A comparison of these two columns shows a general agreement between the NCAP tests and the NASS field data with respect to the combined probability of injury value, as well as for the risk of AIS 3+ injury to the head-face body region. However, the risk of neck injury calculated from the NCAP test data is grossly overstated. The risks to the chest and the knee-thigh-hip are understated. These differences in neck and chest injuries can be traced to the choices of injury risk functions selected for the 2011 NCAP program.

The lack of correlation between the NASS neck injury rates and the NCAP 2011 neck injury rates can be largely attributable to the shape of the Nij injury risk function (Figure 4). The risk function has a non-zero risk intercept for zero Nij (4%) and has a shallow rising slope. Consequently, it can be expected to overstate neck injury risk for Nij values below 1. Eliminating the NCAP Nij and employing only the neck axial force injury risk curve, Figure 5, to compute neck injury risk reduces the 1998-2006 NCAP driver risk from to 7.9% to 0.55%. The revised risk value compares favorably with the 0.7% rate for the neck-spine calculated from the NASS field data.

The right column in Table 9 shows the result of substituting alternative injury risk curves for the neck and chest injury measures. The risk functions used were the Mertz N_{te} neck with no muscle tone (Figure 5) and the Prasad chest function for the older male risk (Figure 3). A comparison of the calculated injury rates using the alternative risk functions and the NASS generated injury rates shows better agreement for the neck and chest injury rates. The alternate chest injury rate is higher than the NASS rate for the population of all ages. However, as shown in Table 6, the chest of older occupants is more vulnerable to injury and increased priority is warranted.

Table 9 shows that 2011 NCAP underestimates the injury rate for chest injuries. The chest injury function applied by NCAP is for a 35 year old male. Figure 2 indicates that this population sustains a risk of AIS 3+ chest injuries in the range of 5% to 10% at NCAP crash severity. Consequently, the 6.8% predicted by NCAP 2011 is in reasonable agreement with the risk to the young population. However, as shown in Figure 1, the older population sustains a much higher injury risk at the NCAP crash severity. Several researchers have noted the substantial increase in chest injury rates with age [Augenstein 2005, Kent 2005]. Most recently, Ridella studied age related injury risks by crash mode and body region and found that the largest age effect was to the thorax in frontal crashes [Ridella, 2011]. Table 6 shows how chest injury rates increase with age and further illustrates the need to prioritize the protection of the chest increases for the older populations. These observations justify the use of chest injury risk functions for older occupants in the revised NCAP rating system.

The lower limb injury rates from the NCAP 2011 risk functions are considerably below the rates in NASS data. However, as shown in Table 5, more than 75% of these the injuries are at the AIS 2 level. When considering the most severe injuries (AIS 4+), as shown in Table 5, the lower extremities represent less than 2% of these injuries. Consequently, the priority for preventing these injuries should be lower than that for preventing serious head, neck and chest injuries. Table 8 indicates that of all the NCAP body regions, the lower limb injury risk is the least sensitive to age. Based on these observations, the use of the NCAP 2011 rating system for lower limb injuries was retained in the rating system for older occupants.

The proposed protocol for older occupants directly addresses the chest protection requirements of older occupants. The example to follow uses the gender-age chest injury risk functions developed by Prasad. [2004, 2010]. Alternative gender-age dependent chest injury risk functions were developed by Laturi. [2005] and could be applied to develop ratings for specific age groups such as 50 year, 65 year, etc.

In summary, the older occupant rating would not change the injury risk curves used by NCAP 1011 for the head and lower limbs. However, the NCAP Nij risk curve would be replaced with the Mertz no muscle tone M_{te} curve (Figure 5). The chest injury risk curve would be replaced by the Prasad injury risk curves for older occupants (Figure 3). The older male curve would be applied to the driver and the older female curve would be applied to the right front passenger.

Table 10 compares the body regions with the highest injury risk when the NCAP 2011 rating scheme is applied and when the older occupant rating scheme is applied. Both the driver and right front passenger are included in Table 10. The body region with the highest injury risk is indicative of the highest priority for injury reduction in order to achieve a higher star rating. The 2011 NCAP data illustrates how the neck risk is the overwhelming leader as the body region with the highest injury risk. In fact for all 2011 NCAP right front passengers, the neck is the body region with the highest injury risk. In contrast, the older occupant rating system shifts the priorities to the chest and lower limbs. This shift is in the general direction suggested by the NASS analysis reported in Table 7.

Table 10.
Body Region at Highest Injury Risk: Alternate Injury Risk Functions for Older Occupants

Body Rehion	Driver		RF Passenger	
	2011 NCAP	Older Male	2011 NCAP	Older Female
Head	0	2	0	8
Neck	60	0	64	0
Chest	3	40	0	27
KTH	1	22	0	29
All	64	64	64	64

The NCAP protocol was followed to develop the elderly rating system. Following NHTSA's star rating protocol, each computed CPI was divided by the reference CPI value giving a relative risk value. The relative risk ratio was used to generate a star rating based on the following boundaries:

0.67 - 5/4 Star Boundary

1.00 - 4/3 Star Boundary

1.33 - 3/2 Star Boundary

2.67 - 2/1 Star Boundary

Table 11.
Alternative Star Rating for Older Occupants

DRIVER STARS	**OLD MALE_50M**					
NCAP 2011	**1**	**2**	**3**	**4**	**5**	**Total**
1						
2						
3	**1**	**6**				**7**
4		**7**	**5**	5	**2**	**19**
5				**8**	15	**23**
Total	**1**	**13**	**5**	**13**	**17**	**49**
PASS. STARS	**OLD FEMALE_5F**					
NCAP 2011	**1**	**2**	**3**	**4**	**5**	**Total**
1						
2	**5**	3	**2**			**10**
3		**1**	3	**4**		**8**
4		**2**	**7**	10	**7**	**26**
5					5	**5**
Total	**5**	**6**	**12**	**14**	**12**	**49**

Table 11 shows the changes in star ratings when the rating system for older occupants is applied to the 2011 NCAP tests. In this table, the rows show the total vehicles for each star rating based on 2011 NCAP tests. The bottom row shows the total vehicles for each star rating based on the older occupant rating system. The matrix shows how the shifts have occurred. For the driver, there has been a general downward shift in the number of stars. However, two vehicles that were 4 star became 5 star. This change suggests that these vehicles with safety features suitable for older drivers are being penalized by the NCAP rating.

In the case of the passenger, the number of 5 star vehicles increased from 5 to 12. There were almost as many increases in star ratings as decreases. These large changes demonstrate that the 2011 NCAP ratings are very sensitive to the injury risk functions used in the star ratings calculations. In particular, as shown in Tables 8 and 9 the injury risk function for the neck has a profound influence on the star ratings.

The changes in star ratings illustrate how the use of alternative risk functions for NCAP test data is a viable alternative for providing consumer information for older consumers.

LIMITATIIONS

The appropriateness of the NCAP test condition in providing a useful rating system to the older population has not been addressed in this paper. Research from an earlier paper suggested that a lower severity crash test would be more representative of the crash environment that produces most of the serious injuries to older occupants [Digges 2007].

The suitability of the Hybrid III dummy's chest compression measurement for use with the chest risk curves is subject to question, based on a recent study [Haight 2013]. The study examined belt geometry in the 2011 and 2012 NCAP tests and found vehicles with the center of the belt 130 mm above the chest deflection transducer on the Hybrid III driver dummy. A distance of 120 mm was observed for the passenger dummy. The sensitivity of the Hybrid III dummy's chest compression measurements to belt positioning has been highlighted in a number of studies. A 1991 study found that by placing the shoulder belt in contact with the neck of a Hybrid III 50^{th} percentile male dummy, versus 50 mm laterally away from the neck resulted in a 34% decrease the chest deflection [Horsch 1991]. Comparative tests reported by JNCAP found that a high belt position resulted in lower chest deflection measurements than a belt positioned lower and closer to the chest transducer [Yamasaki 2011]. The difference in chest deflection exceeded 18 mm. To correct the rating for high belt locations, the injury risk curves would need to be calibrated for the varying belt geometry or the allowable belt geometry would need to be controlled more closely by the NCAP test specification. It should be noted that this deficiency is relevant the existing NCAP as well as to the elderly rating system proposed here.

The appropriate positioning of the 5th female dummy in the right front passenger location requires additional considerations. In a recently reported series of eight 48 km/hr frontal crash tests the 5th female dummy when seated in mid position produced higher chest deflections readings than observed in the NCAP tests at 56 km/hr and with the dummy full forward [Tylko 2012]. Higher readings at the mid position were observed for six of the eight vehicle models tested.

The proposed rating system does not adjust the head and neck injury risks with age. Table 8 shows that head injury rates increase are reasonably constant between the age groupings of 44-64 and 65-97. Both groups have higher rates in the order of 2 to 3 times higher than the 15-43 group. Head injury risk functions for the older groups are not currently available from publications. Consequently, the NCAP 2011 head injury functions were applied to the rating for older occupants. Future ratings for older occupants should apply age related head injury functions, when available.

Like the injury to other body regions, the neck injury rates increase with age. This increase is particularly evident for older women, as shown in Table 8. It would be desirable to apply an age and gender related neck injury function to the rating system for older occupants. Future ratings should apply more age and gender related injury functions when they become available.

CONCLUSIONS

The application of older occupant risk functions to consumer information vehicle tests is feasible and results in significant changes in the star ratings of vehicles tested by NCAP. Such a system would produce added incentives for safety designs that prioritize the reduction of the most frequent injuries experienced by older occupants involved in frontal crashes.

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