INJURY RISK TO SEAT BELT RESTRAINED OCCUPANTS: EFFECT OF AGE AND SEAT ROW

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ABSTRACT

Previous studies have identified an elevated crash injury risk of 8-12 year olds restrained in seat belts compared to their younger counterparts in child restraints. This age group is of particular importance as they represent the transition age between those recommended to use an add-on restraint system such as a booster seat versus those recommended to use the adult seat belt system provided with the vehicle. In order understand the unique restraint needs of this particular age group, research is needed to compare their injury risk to other age occupants following best practice for restraint. Therefore the objective of this project was to compare the injury risk for children and adults who are age-optimally restrained (by seat row and restraint type) and understand the influence of the contributing factors to the risk.

Data were used from the Partners for Child Passenger Safety (PCPS) study and the National Automotive Sampling System (NASS). PCPS data from 1998-2007, collected from crashes reported to an insurance company in 15 states and DC, were used. NASS data from 2000-2009, collected from police reported towaway crashes throughout the US, were used. For both data sets, crashes were limited to vehicles of model year 1998 and newer. For NASS data, efforts were made to limit the crashes to those involving child occupants by identifying typical crash deformation classifications in child-involved crashes.

The AIS 2+ (PCPS and NASS) and AIS3+ (NASS) injury risks were calculated. For PCPS, the following age groups of rear seated occupants were compared: children <1 year of age in rear facing child restraints (RFCRS), children 1-3 years in forward facing child restraints (FFCRS), children 4-7 years in belt-positioning boosters, children 8-12 years in seat belts, and children 13-15 years in seat belts. In addition, the injury risks for children age 13-15 years in seat belts in the front seat were included. For NASS, injury risks were compared for the following rear seated age groups - 8-12 years, 13-15 years, 16-24 years, 25-54 yrs, 55+ years – and front seated age groups - 13-15 years, 16-24 years, 25-54 yrs, 55+ years.

For the PCPS data, compared to children age 1-3 years in FFCRS, rear seated children 8-12 years were 1.9 times more likely to sustain an AIS2+ injury. For the NASS data, rear seated 8-12 year olds had a slightly lower AIS 2+ (2.4%) and AIS 3+ (0.92%) injury risk compared to 25-54 year olds in the front seat (3.2% and 1.2% respectively) (chosen as the reference due to the regulatory focus on this age and seat position) while rear seated 13-15 year olds had a similar injury risk to adults in the front seat. In addition to comparison of the overall injury risks, there are important differences in the body regions of injury that suggest different mechanisms of how the seat belt applies loads across age groups.

INTRODUCTION

For the past several years in the United States, eight years of age has been the recommended age at which one should transition from a belt positioning booster seat and a lap-shoulder belt as the only form of restraint. (NHTSA, 2011) This transition point is reflected in state child restraint laws where the strictest laws prohibit use of a lap shoulder belt alone until the age of 8 years. (IIHS, 2011) In comparison, the Swedish recommendation suggests delaying use of the lap-shoulder belt as the only form of restraint until approximately 10 years of age and a minimum of 135cm height. (Andersson, 2010)

Recent revisions to the American Academy of Pediatrics Best Practice Recommendations for Child Restraint have strengthened and clarified the US recommendations by stating that most vehicle seat belts do not fit children until they are 4’ 9” (145 cm) tall and 8 to 12 years old. (American Academy of Pediatrics, 2011) However, based on NHTSA’s 2009 National Survey of the Use of Booster Seats, 47% of 6 and 7 year olds had already made the transition to seat belts, and only 6% of 8-12 year olds were using

some form of child restraint. (NHTSA, 2010) These findings suggest that while the public health message of encouraging booster seat use well past age 8 years remains important, a detailed understanding the current crash injury risk to 8-12 year olds may reveal insight that leads to the development of alternative restraint countermeasures for this age group.

In order to prioritize countermeasure development, one needs to examine the crash risk associated with seat belt restrained 8-12 year olds in context of the protection provided to other occupants that are following best practice for restraint for their age. By comparing the injury risk to young pre-teenagers restrained in seat belts to both those younger than them in child restraints and those older than them in seat belts, any unique needs associated with this particular age group will be highlighted.

Therefore the objective of this project was to compare the injury risk for children and adults who are age-optimally restrained (by seat row and restraint type) and understand the influence of the contributing factors to the risk.

METHODS

Data were used from the Partners for Child Passenger Safety (PCPS) study and the National Automotive Sampling System (NASS).

PCPS is a large-scale, child specific crash surveillance system: insurance claims from State Farm function as the source of subjects, with telephone survey and on-site crash investigations serving as the primary sources of data. A description of the study methods has been published previously (D. Durbin et al., 2001). Data were collected from December 1, 1998, to November 30, 2007. Passenger vehicles qualifying for inclusion were State Farm–insured, model year 1990 or newer, and involved in a crash with at least one child occupant less than 16 years of age. Qualifying crashes were limited to those that occurred in sixteen states and the District of Columbia, representing three large regions of the United States (East: NY, NJ [through 11/01], PA, DE, MD, VA, WV, NC, DC; Midwest: OH, MI, IN, IL; West: CA, NV, AZ, TX [starting 6/03]).

A stratified cluster sample was designed in order to select passenger vehicles (the unit of sampling) for the conduct of a telephone survey with the driver. Probability sampling was based on two criteria: whether the vehicle was towed from the scene or not and the level of medical treatment received by the child passenger(s). If a vehicle was sampled, the cluster of all child passengers in that vehicle was included in the survey.

Separate verbal consent was obtained from eligible participants for the transfer of claim information from State Farm to Children Hospital of Philadelphia/University of Pennsylvania, for the conduct of the telephone survey, and for the conduct of on-site crash investigations on a smaller convenience sample of crashes. The study protocol was reviewed and approved by the Institutional Review Boards of both the Children's Hospital of Philadelphia and the University of Pennsylvania School of Medicine.

PCPS survey questions regarding injuries to children were classified by body region and severity based on the Abbreviated Injury Scale (AIS) score (1998 version). The ability of parents to accurately distinguish AIS-2 or greater injuries from those less severe has been previously validated for all body regions of injury (Durbin et al., 1999). For the purposes of this study, injury was defined as all injuries with AIS scores of 2 or greater including skull fracture and brain injuries, facial bone fractures, spinal cord injuries, internal organ injuries, and extremity fractures. PCPS data from 1998-2007 were used.

NASS-CDS is a nationally representative database collecting cases from a probability sample of all police-reported, towaway, light motor vehicle traffic crashes in the United States resulting in a range of injury outcomes from no injury to fatality. NASS data from 2000-2009 were used.

For both data sets, crashes were limited to vehicles of model year 1998 and newer and occupants in outboard positions only. For NASS data, crashes were limited to those in which there was a child occupant in the vehicle in an effort to ensure the crashes in which the injury risks were being evaluated were similar across ages.

The primary purpose of these analyses was to compute the adjusted relative risk of injury for age-optimally restrained child and adult occupants by seat row and restraint type. The AIS 2+ (PCPS and NASS) and AIS3+ (NASS) injury risks were calculated. For PCPS, the following age groups of rear seated occupants were compared: children 1-3 years in forward facing child restraints (FFCRS), children 4-7 years in belt-positioning boosters, children 8-12 years in seat belts, children 13-15 years in seat belts. In addition, the injury risks for children age 13-15 years in seat belts in the front seat were included. For NASS, injury risks were compared for the following rear seated age groups - 8-12 years, 13-15 years, 16-24 years, 25-54 yrs, 55+ years – and front seated age groups - 13-15 years, 16-24 years, 25-54 yrs, 55+ years.

Because sampling was based on the likelihood of an injury, subjects least likely to be injured were underrepresented in the study sample in a manner potentially associated with the predictors of interest. Failing to account for the sample design in the

analysis of data would lead to biased estimates of the prevalence of exposures of interest, as well as the outcome, and might also lead to biased estimates of the association between seating position and risk of injury. To account for the stratification of subjects by medical treatment, clustering of subjects by vehicle, and the disproportional probability of selection, Taylor series linearization estimates of the logistic regression parameter variance were calculated using SAS-callable SUDAAN: software for the statistical analysis of correlated data, version 10.0.1 (Research Triangle Institute, Research Triangle Park, NC, 2011). Results of logistic regression modelling are expressed as adjusted odds ratios with corresponding 95% CI. Because injury is a relatively rare event, the odds ratio can be interpreted as a good estimate of relative risk. Adjustments included age/restraint use combinations, vehicle type, driver age, gender, and restraint status, vehicle model year, and crash severity.

RESULTS

For the PCPS data from 12/1/98-11/30/2007, survey information was obtained on 3,995 children in crashes who were weighted to represent 75,400 children. Characteristics of their restraint status and age as well as driver and crash parameters are described in Table 1.

Table 1.
PCPS data (12/1/98-11/30/07) 75,400 weighted (3,995 unweighted)

	% (unweighted n)
Age/Restraint Groups	
<1 year, rear row, RFCRS	6.0 (203)
1-3 years, rear row, FFCRS	24.3 (790)
4-7 years, rear row, BPB	14.7 (446)
8-12 years, rear row, L/S belt	28.2 (1,213)
13-15 years, rear row, L/S belt	10.4 (491)
13-15 years, front row, L/S belt	16.4 (852)
Vehicle type	
Passenger Car	39.2 (1,756)
Cargo Van	1.6 (62)
Pickup Truck	5.9 (230)
SUV	28.1 (1,053)
Minivan	25.2 (894)
Driver Age <25 years	12.4 (646)
Driver Male	29.2 (1,207)
Driver Restrained	97.2 (3,858)
Model Year (2002-2008)	38.1 (1,325)
Crash Severity	
Any Intrusion	2.7 (447)
Any Towaway	36.6 (2,292)
None	60.7 (1,256)
AIS 2+ injury	0.73 (376)

(Limited to M/Y 1998+, outboard seated only)

For the PCPS data, the AIS 2+ injury risks are shown in Figure 1.

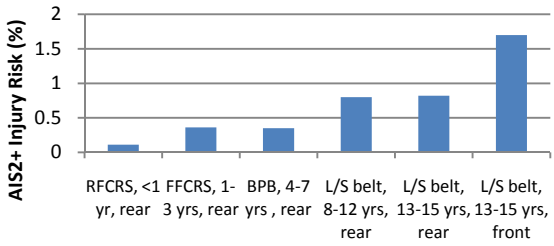

Figure 1.AIS2+ injury risks for those children following age-appropriate restraint best practice.

Compared to children age 1-3 years in FFCRS, rear seated children 8-12 years and 13-15 years were 3.5 and 2.5 times more likely to sustain an AIS2+ injury, respectively. (Table 2) 13-15 year olds in the front seat were 4.8 times more likely to be injured.

Table 2.
AIS2+ injury risk by age-restraint type presented as adjusted odds ratios and 95% confidence intervals (PCPS data)

Restraint/age/seat row	Adjusted OR	95% CI
<1 year, rear row, RFCRS	0.35	0.16-0.77
1-3 years, rear row, FFCRS	Reference	
4-7 years, rear row, BPB	1.76	0.89-3.48
8-12 years, rear row, L/S belt	3.52	2.07-5.95
13-15 years, rear row, L/S belt	2.55	1.58-4.09
13-15 years, front row, L/S belt	4.82	2.96-7.85

In order to gain insight into the mechanisms of these injuries, Table 3 presents the body region specific injury risks for the age-appropriate restraint groupings.

Table 3.
Body region specific AIS 2+ injury rates per 1,000 children in crashes (PCPS data). H: Head, F: Face, C: Chest, A: Abdomen, S: Spine, UE: Upper extremity, LE: Lower extremity

	All	H	F	C	A	S	UE	LE
RFCRS, <1 yr, rear	1.1	0.9	0	0.2	0	0	0	0.4
FFCRS, 1-3 yrs, rear	3.6	1.7	0.4	0.1	0.1	0.1	0.3	1.0
BPB, 4-7 yrs , rear	3.5	2.4	0.2	0.2	0.2	0	0.4	0.5
L/S belt, 8-12 yrs, rear	8.0	3.8	1.0	0.8	1.2	0.2	1.5	0.7
L/S belt, 13-15 yrs, rear	8.2	6.1	0.8	0.6	0.9	0.6	0.8	0.3
L/S belt, 13-15 yrs, front	17	7.9	1.0	3.7	0.4	0.2	3.1	1.8

For the NASS data from 2000-2009, data was obtained on 2,588 subjects in crashes who were weighted to represent 852,601 occupants. Characteristics of the occupants as well as driver and crash parameters are described in Table 4. All subjects are seat belt restrained and all crashes had at least one occupant <16 years of age in the vehicle.

Table 4.
NASS data 2000-2009, 852,601 weighted (2,588 unweighted)

	% (unweighted n)
Age/Row Groups	
8-12 years, rear row	32.0 (662)
13-15 years, rear row	11.9 (328)
16-24 years, rear row	6.5 (182)
25-54 years, rear row	3.9 (120)
55+ years, rear row	0.6 (40)
13-15 years, front row	16.5 (409)
16-24 years, front row	7.7 (234)
25-54 years, front row	17.9 (516)
55+ years, front row	3.0 (97)
Vehicle type	
Passenger Car	50.2 (1,277)
Cargo Van	0.5 (18)
Pickup Truck	7.1 (182)
SUV	25.2 (744)
Minivan	17.0 (367)
Driver Age <25 years	20.9 (623)
Driver Male	39.6 (1,177)
Driver Restrained	96.4 (2,506)
Model Year (2002-2010)	48.2 (1,381)
AIS 2+ injury	3.15 (290)
AIS3+ injury	1.28 (149)

For the NASS data, rear seated 8-12 year olds had a slightly lower AIS 2+ and AIS 3+ injury risk compared to 25-54 year olds in the front seat while rear seated 13-15 and 16-24 year olds had a similar injury risk to adults in the front seat. (Figure 2)

Rear seated 8-12 year olds had a slightly lower AIS 2+ and AIS 3+ injury risk compared to 25-54 year olds in the front seat while rear seated 13-15 and 16-24 year olds had a similar and potentially elevated injury risk to adults in the front seat. (Table 5)

Table 5.
AIS2+ and AIS 3+ injury risk by age-seat row presented as adjusted odds ratios and 95% confidence intervals (NASS data)

Age/seat row	AIS2+ Adj. OR	95% CI	AIS3+ Adj.OR	95% CI
8-12 years, rear row	0.81	0.45-1.45	0.81	0.33-2.01
13-15 years, rear row	1.31	0.60-2.87	1.03	0.37-2.88
16-24 years, rear row	1.10	0.56-2.17	1.67	0.64-4.35
25-54 years, rear row	1.26	0.52-3.02	1.71	0.43-6.81
55+ years, rear row	3.92	1.03-14.92	2.72	0.53-13.87
13-15 years, front row	0.74	0.29-1.86	0.79	0.40-1.56
16-24 years, front row	0.79	0.36-1.72	0.99	0.46-2.13
25-54 years, front row	Reference			
55+ years, front row	1.92	0.67-5.51	1.69	0.48-5.93

Table 6a and 6b presents the body region specific injury risks (AIS 2+ and AIS3+) for the age-seat row groupings.

Table 6a.
Body region specific AIS 2+ injury rates per 1,000 occupants in crashes (NASS data). H: Head, F: Face, C: Chest, A: Abdomen, S: Spine, UE: Upper extremity, LE: Lower extremity

	H	F	C	A	S	UE	LE
8-12 years, rear	4.7	4.2	3.0	4.8	1.6	8.2	5.1
13-15 years, rear	15.3	3.9	7.2	2.1	2.8	10.1	15
16-24 years, rear	19.9	8.1	15.3	8.3	2.3	11.3	8.8
25-54 years, rear	10.8	0	2.6	0.8	11.7	23.3	1.9
55+ years, front	11.8	3.9	12.7	6.0	18.9	27.9	30
13-15 years, front	5.8	0.2	4.1	1.8	2.4	3.4	18.4
16-24 years, front	7.7	5.6	8.7	0.9	0.3	12.6	10.4
25-54 years, front	5.6	0.9	5.9	1.4	2	17.3	8.6
55+ years, rear	61.6	0	34.6	26.3	9.6	20.4	12.3

Table 6b.
Body region specific AIS 3+ injury rates per 1,000 occupants in crashes (NASS data). H: Head, F: Face, C: Chest, A: Abdomen, S: Spine, UE: Upper extremity, LE: Lower extremity

	H	F	C	A	S	UE	LE
8-12 years, rear	1.4	3.8	3	0.7	0.8	0.4	1.4
13-15 years, rear	1.4	0	7.2	1.5	1.7	3.7	5.8
16-24 years, rear	9.5	0	14.2	6.5	0.3	0	0.8
25-54 years, rear	9.8	0	1.2	0	1.7	8.2	0.5
55+ years, front	11.8	0	8.8	0.4	6.6	11.3	7.3
13-15 years, front	1.2	0	4.1	1.3	1.8	1.3	4
16-24 years, front	1.6	0	8.5	0.8	0	2.5	5.7
25-54 years, front	2.6	0	3.4	0.8	1.3	3.4	4.5
55+ years, rear	1.7	0	18.4	16.7	9.6	0	7.9

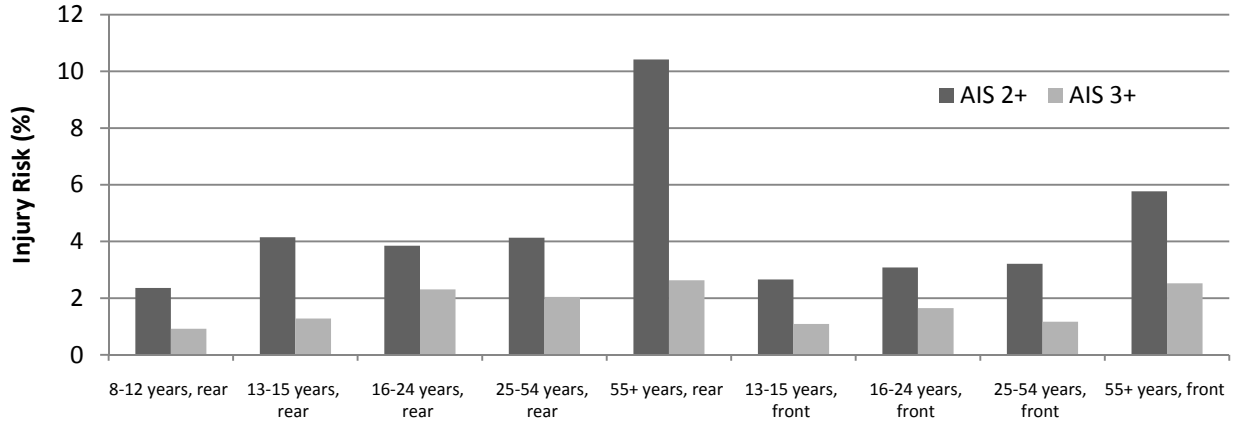

Figure 2. AIS2+ and AIS 3+ injury risks for seat belt restrained occupants stratified by age and seat row (NASS data).

DISCUSSION

This paper compared to injury risks of 8-12 year old seat belt restrained occupants with those younger than them in child restraints as well as those older than them in seat belts. All occupants studied were following best practice restraint recommendations for age. This age group represents the transition point between add-on restraint systems and using the vehicle provided seat belt system.

Compared to their younger counterparts, seat belt restrained child occupants age 8-15 years were at elevated risk of AIS 2+ injury. Specifically compared to children age 1-4 years in forward facing child restraints, those 8-12 years restrained in seat belts were 3.5 time more likely to sustain an AIS2+ injury. While head injuries were the most common body region of injury for all age groups, those 8-12 years old had involvement of many other body regions in their injury pattern. In particular, injuries to the chest and abdomen become more prominent. The injury risk to 8-12 year olds in the rear seat is very similar compared to rear seated teenagers – age 13-15 years – many of whom are adult size. As expected when these teenagers move the front seat, their injury risk doubles reflecting current knowledge about the elevated risk associated with front seating (Arbogast et al, 2009).

In the analyses comparing the 8-12 year old rear seated occupants to similarly restrained adult occupants using NASS data, this paper implemented novel methodology of restricting the adult crashes to those in which a child less than 16 years of age was in the vehicle. The premise of this methodological step was the hypothesis that crashes involving child occupants are different in key characteristics than crashes with no child occupants in the vehicle. An evaluation of how age modulates the protection provided by the adult seat belt must compare across similar crashes. For example, if adults (without children in the vehicle) are in more severe crashes (e.g. different crash types, different delta v) then their injury risk in the same restraint may be higher for reasons that are not related to the age-related performance of the seat belt. This may bias the comparison between pre-teen and adult occupants restrained in seatbelts in a way that masks any potential elevated injury risk in the child. However, in our current sample of similar crashes, compared to rear seated adults age 25+ years, the child injury risk was lower. Future analyses will formally test the hypothesis of differences in crash characteristics between child-involved and non-child involved crashes.

Compared with 25-54 year old occupants in the front row (chosen as the reference due to the regulatory focus on this age and seat position), pre-teen and teenage occupants show non-significant differences in AIS2+ injury risk. The point estimates for 8-12 year olds show a lower injury risk compared to adults in the front seat while that for the 13-15 year olds is elevated. Similar trends exist for AIS3+ injury. The lack of statistical significance of these findings suggests typical benefits associated with rear seating may not be fully realized for these younger age groups. For those 8-12 years of age, compared to other age groups, the importance of abdominal injuries and the decreased incidence of thoracic injuries are notable. Future research should explore the specific anatomic diagnoses of these injuries and investigate specific mechanisms to understand further how the seatbelt (both the lap and shoulder portion) may apply loads differently to these age groups.

One limitation of this study is evidenced by the large confidence intervals, due to limited sample size of children and adults age 13+ years in the rear seat. Furthermore, the strategy of limiting the adult crashes to those in which a child occupant was also in the vehicle substantially contracted the adult population available to study. While the authors remain convinced this step is critical to the line of analyses, other analytical methods to ensure comparison of the age-modulated injury risk associated with seat belt restraints is being made across similar crashes needs to be explored.

CONCLUSIONS

This paper provides a comparison of injury risks for those occupants who are following best practice for their age – in seat position and restraint type with a particular focus on those 8-12 years as they represent the transition point between the use of add-on restraint systems and using the restraints provided with the vehicle. The analysis attempts to ensure a comparison of risks across similar crash conditions by limiting the adult data to those crashes in which a child occupant is in the vehicle.

A principal finding is the elevated injury risk experienced by 8-12 year old child occupants who are following best practice for seat belt restraint. Using PCPS data, compared to children in forward facing child restraints, rear seated, seat belt restrained 8-12 year olds are at 1.9 times increased risk of AIS 2+ injury. However in comparison to 25-54 year olds in the front seat, NASS data analyses demonstrated that rear seated 8-12 year olds had a slightly lower but non-significant AIS 2+ and AIS 3+ injury risk.

Similarities between 8-12 year old injury risk in the rear seat and 25-54 year old injury risk in the front seat suggests typical benefits associated with rear seating may not be fully realized for this younger age group.

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REFERENCES

American Academy of Pediatrics (2011) Technical Report of Child Passenger Safety. Pediatrics 127 (4).

Andersson M, Bohman K, Osvalder AL. (2010) Booster design effect on children's choice of seating position during naturalistic riding. Proc. 54th Annual AAAM. Las Vegas. USA. pp.171-80.

Arbogast KB, Kallan MK, Durbin DR. (2009) Front versus Rear Seat Injury Risk for Child Passengers: Evaluation of Newer Model Year Vehicles. Traffic Injury Prevention 10(3): 297-301.

Durbin D, Bhatia E, Holmes J, ShawK,Werner J, SorensonW,Winston F. (2001) Partners for Child Passenger Safety: A Unique Child- Specific Crash Surveillance System. Accid. Anal. Prev., Vol. 33, pp.407–412.

Insurance Institute for Highway Safety. (2011) http://www.iihs.org/laws/restraintoverview.aspx.

National Highway Traffic Safety Administration. (2010) The National Survey of the Use of Booster Seats (NSUBS). DOT HS 810 951.

National Highway Traffic Safety Administration. (2011) http://www.nhtsa.gov/Safety/CPS.