EFFECTIVENESS OF HIGH BACK AND BACKLESS BELT-POSITIONING BOOSTER SEATS IN SIDE IMPACT CRASHES

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ABSTRACT

Previous work quantified a 59% reduction in injury risk for children in belt positioning booster seats (BPB) compared to those restrained in seat belts using a sample of crashes of all directions of impact. Experimental sled tests have highlighted the potential for extreme occupant excursion out of the BPB in side impact crash conditions. Using data from a large child specific crash surveillance system, the present study built upon these previous studies and quantified the relative effectiveness of BPB as compared to seat belts in reducing the risk of injury among 4-8 year olds in side impact crashes. Children in BPB were at a 58% reduction in risk of injury than those in seat belts in side impact crashes. This result varied by booster seat type: those in high back BPB were at a 70% reduction in injury risk while those in backless BPB did not experience a statistically significant reduction in injury risk compared to those in seat belts. This differential performance of the two types of BPB provides direction for future research into the design and performance of these restraints.

The protection of children in side impacts has attracted considerable attention in the safety community as these crashes represent a significant burden on society. Analyses of the Fatal Analysis Reporting System (FARS) demonstrated that 42% of the fatalities of rear seat child occupants age 0-8 were in side impact crashes (National Highway Traffic Safety Administration 2003).

Several studies have examined the injury and fatality pattern for children in side impact crashes. In analyses of children from 0-14 years of age admitted to a trauma center, Orzechowski et al documented injuries of elevated severity in side impacts as compared to frontal crashes and further identified a pattern of injuries in side impact crashes to include those to the head, cervical spine and chest (Orzechowski et al. 2003). Our previous work demonstrated that the benefits of rear seating previously shown for frontal crashes extended to side impact crashes for children age 0-15 years (Durbin et al. 2001). Howard et al examined the role of seat position on the injury risk to children age 0-12 years in side impact crashes using a sample of children admitted to two trauma centers as well as analyses of the National Automotive Sampling System (NASS) and FARS. In this study, the elevated injury and fatality risk associated with the struck side seat position was highlighted (Howard et al. 2004). All of these studies focused on children of a broad age range, thus including an array of restraint conditions limiting the applicability of the findings to a particular restraint type. Only two studies have focused their study of side impact protection for children on a specific restraint: both examined injury or fatality risk to children in harnessed-based child restraint systems (Sherwood et al. 2003; Arbogast et al. 2004).

In the past five years, there has been tremendous focus on the benefits of booster seats as compared to seat belts. In a study of 4-7 year olds, those in belt-positioning booster seats (BPB) experienced a 59% reduction in injury risk compared to those restrained in seat belts (Durbin et al. 2003). This analysis was conducted on a study sample that, although it included all directions of impact, was composed of over 50% frontal crashes. To date, no study has examined the field performance of these restraints in side impact crashes. Experimental sled tests have highlighted the potential for extreme occupant excursion out of the BPB in lateral crash conditions. In a test matrix utilizing high back and backless BPB in 30- and 90-degree far side impacts, significant lateral movement was present in both restraint systems exacerbated by relative slipping between the booster seat and the vehicle seat. The dummy's upper torso slipped out of the shoulder belt in all tests resulting in large head excursions and the potential for head contact with vehicle interior (Mallot et al. 2004).

Therefore, the objective of this analysis was to build on previous work and determine if the previously documented benefits of BPB over seat belts in reducing child injury risk extend to side impact crashes. Specifically, we quantified the relative effectiveness of belt-positioning booster seats, both backless and high back, as compared with seat belts alone in reducing the risk of injury among 4-8 year old children in side impact crashes.

METHODS

STUDY POPULATION AND DATA COLLECTION - Data for the current study were drawn from the Partners for Child Passenger Safety (PCPS) program, collected from December 1, 1998 to December 31, 2004. A description of the study methods has been published previously (Durbin et al. 2001). PCPS consists of a large scale, child-specific crash surveillance system: insurance claims from State Farm Insurance Co. (Bloomington, IL) function as the source of subjects, with telephone survey and on-site crash investigations serving as the primary sources of data.

Vehicles qualifying for inclusion were State Farm™-insured, model year 1990 or newer, and involved in a crash with at least one child occupant ≤15 years of age regardless of restraint status. Qualifying crashes were limited to those that occurred in fifteen states and the District of Columbia, representing three large regions of the United States (East: NY, NJ [until 11/01], PA, DE, MD, VA, WV, NC, DC; Midwest: OH, MI, IN, IL; West: CA, NV, AZ, TX [starting 6/03]). After policyholders consented to participate in the study, limited data were transferred electronically to researchers at The Children's Hospital of Philadelphia and University of Pennsylvania. Data in this initial transfer included contact information for the insured, the ages and genders of all child occupants, and a coded variable describing the level of medical treatment received by all child occupants. Valid levels of medical treatment were no treatment, physician's office or emergency department only, admitted to the hospital, or death.

A stratified cluster sample was designed in order to select vehicles, the unit of sampling, for the conduct of a telephone survey with the driver. In the first stage of sampling, vehicles were stratified on the basis of whether they were towed from the scene or not, and a probability sample of both towed and nontowed vehicles was selected at random, with a higher probability of selection for towed vehicles. In the second stage of sampling, vehicles were stratified on the basis of the level of medical treatment received by child occupant(s). A probability sample from each tow status/ medical treatment stratum was selected at random with a higher probability of selection for vehicles in which a child occupant died, was admitted to the hospital, or evaluated in a physician's office or emergency department. In this way, the majority of injured children would be selected while maintaining the representativeness of the overall population. If a vehicle were sampled, the "cluster" of all child occupants in that vehicle were included in the survey.

Drivers of sampled vehicles were contacted by phone and screened via an abbreviated survey to verify the presence of at least one child occupant with an injury. Surveys were conducted only in English. All vehicles with at least one child who screened positive for injury and a 10% random sample of vehicles in which all child occupants screened negative for injury were selected for a full interview. The full interview involved a 30-minute telephone survey with the driver of the vehicle and parent(s) of the involved children.

Only adult drivers and parents were interviewed. The median length of time between the date of the crash and the completion of the interview was six days.

The eligible study population consisted of all 663,266 children riding in 447,924 State-Farm-insured vehicles newer than 1990 reporting a crash claim between December 1, 1998 and December 31, 2004. Claim representatives correctly identified 96% of eligible vehicles, and 70% of policyholders consented for participation in this study. Of these, 18% were sampled for interview and an estimated 81% of these were successfully interviewed.

For a subset of cases in which child occupants were admitted to the hospital or killed, in-depth crash investigations were performed. Cases were screened via telephone to confirm the details of the crash. Contact information from selected cases was then forwarded to a crash investigation firm (Dynamic Science, Incorporated, Annapolis, MD), and a full-scale on-site crash investigation was conducted using custom child-specific data collection forms. For the purposes of this analysis, these cases were used to examine the validity of information obtained from the telephone survey.

VARIABLE DEFINITIONS – Seating location and restraint use of each child were determined from a series of questions in the telephone survey. Among 528 children for whom paired information on seating position (front versus rear) was available from both the telephone survey and crash investigations, agreement was 99% between the driver report and the crash investigator (kappa=0.98, $p<0.001$). Among 511 children for whom paired information on type of restraint use was available from both the telephone survey and crash investigations, agreement was 87% between the driver report and the crash investigator (kappa=0.77, $p<0.001$). Direction of first impact was derived from a series of questions regarding the vehicle parts that were involved in the first collision. Side impact crashes were defined as crashes in which the vehicle parts involved in the first collision were on the lateral plane of the vehicle. Crash severity was determined by driver report of intrusion into the occupant compartment of the vehicle via the telephone survey.

Survey questions regarding injuries to children were designed to provide responses that were classified by body region and severity based on the Abbreviated Injury Scale (AIS) score (1990). 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, "injuries" were defined as those deemed clinically significant: all injuries with AIS scores of 2 or greater including concussions and more serious brain injuries, facial bone fractures, spinal cord injuries, internal organ injuries, and extremity fractures, as well as those injuries with potential for disfigurement, specifically facial and scalp lacerations.

Separate verbal consent was obtained from eligible participants for the transfer of claim information from State Farm to CHOP/Penn, for the conduct of the telephone survey, and for the conduct of the crash investigation. 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.

DATA ANALYSIS – The primary purpose of these analyses was to compute the relative risk of injury for children aged 4 to 8 restrained in belt-positioning booster seats as compared with seat belts in side impact crashes. Age 4 was chosen as the lower bound for our analyses because current recommendations for optimal restraint indicate that children < 4 years of age should be restrained in child safety seats (American Academy of Pediatrics 2003). The study sample was restricted to rear row occupants and those children 30-80 pounds to remove particularly small or large children within the studied age range.

Chi-square tests of association were used to compute p-values under the null hypothesis of no association between restraint type and risk of injury. Logistic regression modeling was used to compute the odds ratio (OR) of injury for those seated in belt-positioning booster seats versus seat belts, both unadjusted and adjusted for several potential confounders including driver age (< 25 years vs. 25 and older), seating position (struck side, non-struck side, center), crash severity (intrusion and towaway), model year, and vehicle type.

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. To compute p-values and 95% confidence intervals 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 9.0 (Research Triangle Institute, Research Triangle Park, NC, 2004). Results of logistic regression modeling are expressed as unadjusted and adjusted odds ratios with corresponding 95% confidence intervals.

RESULTS

This analysis was restricted to 752 side impact crashes involving 889 children aged 4-8 years, weighted to represent 12,581 children in 10,728 crashes. Overall 78% were restrained by seat belts and 22% were restrained in belt positioning booster seats (BPB). Of those in BPB, 84% were using high back BPB. Table 1 provides the distribution of child age, vehicle type, model year, seat position, driver age, and crash severity among 4-8 year olds restrained in seat belts and in belt-positioning booster seats. Within the study sample of 4-8 year olds, restraint use of the children varied by age. 47% of children using seat belts were 7-8 years old while 69% of those using BPB were 4-5 years old (p<0.001). There was also a difference in seating position between the two main restraint types. A greater percentage of those in seat belts sat in the center rear (20%) than those in BPB (3%) (p<0.001). There were no differences in vehicle type, model year, driver age, and crash severity proxies such as intrusion and towaway status between those in seat belts and those in BPB. None of the parameters (including child age and seat position) showed any significant differences between high back BPB and backless BPB.

Table 1: Characteristics of children restrained in seat belts BPB in side impact crashes. Data are presented as weighted column % with unweighted n in parentheses.

	Seat belts (weighted n=9,844)	Belt positioning boosters (BPB) (weighted n=2,737)	High back BPB (weighted n=2,310)	Backless BPB (weighted n=427)	p-value*
Age (years)					
4	13.0 (100)	36.8 (53)	39.7 (45)	20.7 (8)	<0.001
5	18.1 (147)	32.3 (40)	28.3 (31)	54.1 (9)	
6	22.2 (152)	22.6 (34)	24.4 (28)	12.6 (6)	0.32
7-8	46.8 (349)	8.3 (14)	7.5 (8)	12.6 (6)	
Vehicle type					
Passenger Car	45.9 (370)	41.7 (61)	40.4 (46)	48.4 (15)	
SUV	3.3 (22)	3.0 (4)	3.5 (2)	0.5 (2)	0.94
Minivan	5.7 (28)	4.5 (5)	5.2 (4)	0.2 (1)	
Pickup Truck	19.6 (132)	23.3 (34)	21.9 (28)	30.9 (6)	0.48
Cargo Van	25.5 (196)	27.6 (37)	29.0 (32)	20.0 (5)	
Model year					
1990-1993	19.2 (145)	11.3 (16)	9.8 (12)	19.2 (4)	0.19
1994-1997	32.8 (273)	34.8 (52)	38.8 (45)	12.9 (7)	0.10
1998-2005	47.9 (330)	53.9 (73)	51.4 (55)	67.9 (18)	
Seat position					
Struck side	43.0 (313)	54.3 (79)	53.5 (64)	58.1 (15)	<0.001
Non-struck side	37.1 (286)	42.7 (58)	44.7 (47)	32.1 (11)	0.56
Center rear	19.9 (149)	3.0 (4)	1.7 (1)	9.8 (3)	
Driver age <25 years	5.1 (56)	6.0 (9)	5.8 (6)	7.0 (3)	0.75 0.82
Intrusion	17.2 (304)	12.7 (47)	14.3 (39)	4.0 (8)	0.25 0.06
Towaway	39.2 (523)	36.4 (93)	36.4 (71)	36.0 (22)	0.64 0.98

*1st p-value (seat belts vs. BPB), 2nd p-value (high back BPB vs. backless BPB)

Injuries occurred to 1.8% of all 4-8 year-olds, including 2.1% of those in seat belts and 0.8% of those in belt-positioning booster seats. (Figure 1) The unadjusted odds of injury in side impact crashes were 62% lower for children aged 4-8 in belt-positioning boosters than in seat belts (OR=0.38, 95% CI=0.22-0.66). Adjusting for crash severity, vehicle type, seat position, age of driver, and model year yielded an estimated adjusted reduction in risk of 58% (OR=0.42, 95% CI=0.21-0.83).

The benefit of belt positioning boosters as compared to seat belts varied by booster seat type. The injury risk was 0.6% and 1.9% in high back and backless belt positioning booster seats, respectively. (Figure 1) Comparing these injury risks to those of children restrained in seat belts, the adjusted odds of injury were 70% lower for children in high back belt positioning booster seats (OR=0.30, 95% CI=0.13-0.68), while the adjusted odds of injury were not statistically different for children in backless belt positioning booster seats (OR=1.17, 95% CI=0.40-3.43).

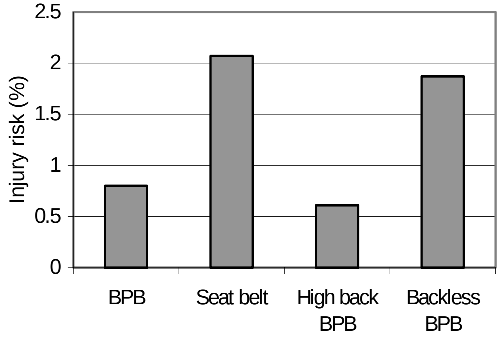

Figure 1: Injury risk for 4-8 year old children, weighing 30-80 pounds, in side impact crashes. Injury risks are shown for children restrained in belt positioning booster seats (BPB), seat belts, high back BPB, and backless BPB.

Table 2 provides the distribution of the body regions of injury for children in belt-positioning booster seats (both high back and backless) and seat belts. Children in seat belts suffered injuries to every body region. However, children in either type of belt-positioning booster seat suffered injuries only to the head, face, and lower extremity.

Table 2: Distribution of body regions of injury for children in belt positioning booster seats and seat belts. n=unweighted number of injuries.

	Seat belts (n=204)	Belt positioning boosters (BPB) (n=22)	High back BPB (n=14)	Backless BPB (n=8)	Unadjusted OR (95% CI)*
Head	1.46 (102)	0.40 (11)	0.22 (5)	1.40 (6)	0.27 (0.13-0.56) 0.15 (0.04-0.58)
Face	0.59 (58)	0.44 (12)	0.43 (10)	0.47 (2)	0.74 (0.38-1.46) 0.92 (0.18-4.75)
Chest	0.03 (3)	0.04 (1)	0.04 (1)	0.00 (0)	1.20 (0.12-11.75) n/a
Abdomen	0.09 (9)	0.00 (0)	0.00 (0)	0.00 (0)	n/a n/a
Neck/spine /back	0.03 (3)	0.00 (0)	0.00 (0)	0.00 (0)	n/a n/a
Upper Extremity	0.17 (14)	0.00 (0)	0.00 (0)	0.00 (0)	n/a n/a
Lower Extremity	0.13 (13)	0.07 (2)	0.04 (1)	0.23 (1)	0.55 (0.12-2.51) 0.18 (0.01-3.17)

*****1st set of OR's compare seat belts vs. BPB, 2nd set of OR's compare high back BPB vs. backless BPB

DISCUSSION

The benefits of belt positioning booster seats for young children have been well documented. Our previous work, on a study sample of crashes of all impact directions, quantified a 59% reduction in injury risk for those children age 4-7 restrained in BPB over those restrained in seat belts (Durbin et al. 2003). The current study extended that previous work and quantified the relative effectiveness of BPB as compared to seat belts in reducing the risk of injury among 4-8 year olds in side impact crashes. Specifically children in BPB were at a 58% reduction in risk of injury than those in seat belts in side impact crashes.

Children in seat belts sustained injuries to all body regions, while those in BPB sustained only injuries to the head, face, and lower extremity. Although not of the same magnitude as our previous study of primarily frontal crashes, of note is the constellation of injuries known as seat belt syndrome, which includes injuries to the abdomen and neck/back/spine. Use of either type of booster seat resulted in the absence of these injuries in this sample.

Abdominal injuries to children in seat belts in side impact crashes occur differently than the forward jackknifing over the seat belt commonly associated with frontal crash conditions. Abdominal injuries can occur in center rear and non-struck side belted occupants by lateral bending over the belt (Maltese et al. 2005). For struck side occupants, a potential mechanism of injury is contact with the interior door surface, in particular the armrest (Arbogast et al. 2001).

Previous work has documented that in a side impact collision, discontinuities in the loading surface (both indentations as well as protuberances) can cause significant injury (Rouhana 1989; Lau 1991). A young child in a seat belt will interact with the door at a different location than a young child in a booster seat whose lateral profile is more adult-like due to the lift provided by the BPB. For those children, the armrest may contact much lower, most likely interacting with the bones of the pelvis or the BPB itself rather than the internal abdominal organs.

Further benefits of BPB over seat belts were realized from a reduction in head injuries with a trend towards reduction in facial injuries. Most of these injuries are likely derived from contact mechanisms suggesting a role of BPB of controlling upper torso and head excursion. Children in seat belts with a lower seated height also are more likely to contact the interior door panel below the belt line, areas not necessarily tested as part of FMVSS 201, Occupant Protection in Interior Impact (Arbogast et al. 2002; Orzechowski et al. 2003).

The extremely few chest injuries in either restraint in this study are in contrast to previous research on child occupant protection in side impacts. Orzechowski et al studied children age less than 14 years admitted to a trauma center and documented that 35% of them sustained an AIS2+ injury to the chest (Orzechowski et al. 2003). Howard and colleagues in a study of children 0-12 years from a sample from two trauma centers identified 3 chest injuries out of 23 struck side child occupants (Howard et al. 2004). A likely explanation for the differences between the studies is the differences in populations studied. Both previous studies sampled children who were admitted to a trauma center and thus sustained a greater level of injury severity than our study that included all crashes reported to an insurance company.

The benefit of BPB in reducing injury risk compared to seat belts varied by booster seat type: those in high back BPB were at a 70% reduction in injury risk while those in backless BPB did not experience a statistically significant reduction in injury risk compared to those in seat belts. The elevated injury risk in backless BPB (as compared to high back BPB) is primarily derived from excess injuries to the head. There are several potential explanations for this result. First, anecdotal evidence suggests that most who use a backless BPB do not use the shoulder belt positioner that is attached by a strap of webbing to the bottom of the seat but rather rely on the natural position of the shoulder belt on the child. Especially for the youngest children, this practice likely leads to better shoulder belt positioning on the child’s clavicle in those in high back boosters, which have a specific router for the shoulder belt. Better positioning will allow for a better hold on the upper torso in far side impact crashes which has been demonstrated for adults to lead to decreased upper body displacement and head acceleration (Horsch 1980).

Second, the defining characteristic of a high back BPB is the fact that is has a back, most of which are slightly contoured to contain the occupants. Several studies examining far side occupant protection in adults have evaluated the effect of contoured seats (termed lateral wing seat bolsters, winged-seats) on occupant kinematics and injury metrics and documented that such a design helps contain the occupant and direct them more forward into the restraint (Horsch 1980; Culver and Viano 1981; Stolinski 1999). The current analyses suggest that a similar kinematic effect may be occurring in high back BPB. Review of data from our previous sled test matrix reveals that in oblique far side crashes, test dummies in high back BPB experience higher shoulder belt loads, chest deflection, and chest acceleration than backless BPB providing further support of this hypothesis (Mallot et al, 2004).

Lastly, caution should be exercised when interpreting the data from the two different types of BPB. Although statistically significant results were present, small sample sizes, particularly in the backless BPB, lead to a level of uncertainty in the findings. However, the non-detectable difference between seat belts and backless BPB in side impact crashes in this analysis deserves further study.

LIMITATIONS

This research is conducted on crashes involving State Farm Insurance Co. policyholders only. State Farm is the largest insurer of automobiles in the United States, with over 38 million vehicles covered; therefore, its policyholders are likely representative of the insured public in this country. The surveillance system is limited to children occupying model year 1990 and newer vehicles insured in 16 states and the District of Columbia. Our study sample represents the entire spectrum of crashes reported to an insurance company including property damage only, as well as bodily injury crashes. While our sample included a significant number of vehicles with intrusion into the occupant compartment, it is possible that we do not have a representative sample of the most severe crashes.

Nearly all of the data for this study were obtained via telephone interview with the driver/ parent of the child and is, therefore, subject to potential misclassification. On-going comparison of driver-reported child restraint use and seating position to evidence from crash investigations has demonstrated a high degree of agreement. In addition, our results on age-specific restraint use and seating position are similar to those of other recently reported population-based studies of child occupants (Edwards and Sullivan

1997; Wittenberg et al. 1999). Therefore, it is unlikely that errors in reporting restraint use or seating position would substantially alter the results of this study.

Data on the injuries sustained have been obtained via a validated telephone survey – more specific details from medical records may provide insight regarding the mechanisms of injury. Thus, it is important to note, however that these comparisons only look at injury risk and do not assume similar mechanisms of injury. Further the injury risks presented are for AIS2+ injury. These surveillance data cannot detect if those in seat belts are sustaining primarily AIS3-4 injuries while those in backless BPB are experiencing only AIS2 injuries. Side impact crashes as defined in the PCPS surveillance system include those crashes in which the point of first contact is on the lateral plane of the vehicle. Understanding the role of impact angle and specific horizontal location of impact are obtained through review of the in-depth cases only.

Lastly, the automotive crash environment is evolving; the results presented herein are based upon vehicle model years 1990 to 2005 exposed to crash environments between calendar years 1998 and 2004, and changes in restraint practice, fleet composition, and safety system design over time may yield different results in future research studies.

CONCLUSIONS

The effectiveness of BPB in reducing injuries to children 4-8 years of age applies to side impact crashes. Benefits are obtained by reduction of injuries to the head and face as well as the pattern of injuries to the abdomen and spine known as seat belt syndrome. The data suggest that this benefit is primarily realized for high back BPB. Backless BPB do not demonstrate a statistically significant reduction of injury risk compared to seat belts in side impact crashes. This result may be due to geometrical differences between the two types of BPB: namely the presence of a specific belt path for the shoulder belt and the contoured back of the high back BPB. Both design components may serve to better contain the occupant in these crashes thus resulting in improved protection. This differential performance provides direction for future research into the design and experimental performance of these restraints.

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