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CPS ISSUE REPORT

ISSUE FIVE: OPTIMIZING THE REAR SEAT FOR CHILDREN – APRIL 2013

The Children's Hospital *of* Philadelphia®

RESEARCH INSTITUTE

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- Translates rigorous scientific research to usable, age-appropriate tools and practical steps for families, professionals and policymakers
- Asks and answers important questions from an interdisciplinary perspective, with expertise in Behavioral Science, Clinical Care, Engineering, Epidemiology and Biostatistics, Human Factors, Public Health, and Communications
- Engages with a broad range of organizations, from universities and government entities to nonprofit groups, foundations and corporations, to ensure that research results extend to the real world

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Optimizing the Rear Seat for Children

Children are the primary occupants of the rear seat of passenger vehicles. In fact, 70 percent of rear seat occupants are children less than 14 years old. Children under age 16 spend nearly as much time in motor vehicles as adults, averaging 3.4 trips per day for a total of 45 to 50 minutes. Today's kids spend more time being transported in passenger vehicles than previous generations and merit equal consideration when prioritizing vehicle safety for occupants.

This report explores the state of the science on safety for children and youth in the rear seat and makes recommendations for how industry and government can prioritize resources to optimize the space to enhance safety.

During the past decade, the United States has made remarkable progress in reducing the overall burden of child traffic fatalities. From 2001 to 2010, fatalities for children age 15 and younger in passenger vehicles have dropped 46 percent from 1,775 to 952. This achievement can be attributed to several factors:

- Due to a combination of laws and education, increases in age-appropriate restraint use and rear seating for children under age 13 have occurred.
- Regulations have required lap and shoulder belts in all rear row positions since 2004, as well as lower and upper anchorages to secure child restraint systems (CRS) without seat belts, which were phased in between 1999 and 2002.
- Vehicles in general have improved their safety for all occupants by including advanced crash-mitigating technology, such as Electronic Stability Control.

Despite this progress, there is still an unacceptable number of our young dying in crashes — 952 deaths among children ages 15 and younger in 2010. Motor vehicle crashes remain the leading cause of death and disability for children and youth age 4 years and older.

In April 2011, the American Academy of Pediatrics (AAP) reconfirmed its best practice recommendation that all children younger than 13 years should be restrained in the rear seats of vehicles for optimal protection. The AAP cited several studies that documented the benefits of rear seating for children. These studies provide estimates of the elevated risk of injury ranging from 40 to 70 percent for children in the front seat as compared with children seated in the rear. Injuries suffered by children in the front seat tend to be more severe than for those in the rear rows. Research also showed that the protective benefits of rear seating were not as strong for children 13 years and older.

There is strong evidence that use of a CRS is protective. Children properly restrained in a child restraint system have an injury risk of 4 per 1,000 children in tow-away crashes, and those in booster seats are similarly protected (injury risk of 5.5 per 1,000 children). However, as children grow older and move out of these special restraints, their risk of serious injury and death increases.

According to 2007 data from the Partners for Child Passenger Safety study, injuries increased with age: 4.5 injuries per 1,000 children for 0 to 3 years, 7.0 for 4 to 8 years, 15.5 for 9 to 12 years, and 20.6 for 13 to 15 years. This is due in part to the different ways they are restrained at each age, where they sit and other crash characteristics. In addition, as children age, the vehicle's rear seat and associated safety features may not be able to offer the optimal protection that younger occupants are provided by add-on restraints.

Safety features such as advanced frontal and side impact air bags, seat belts with load limiters and pretensioners, and active head restraints have largely been integrated as standard front seat features but are less commonly found as either

continued on next page

Nationally representative statistics suggest that we need to better protect older children who outgrow child safety seats and booster seats.

continued from Optimizing the Rear Seat for Children

standard or optional equipment in the rear seat. The integration of these technologies into the front seat may have resulted in improvement in protection in the front seat that has not been realized in the rear seats. As a result, if our youth are following best practice recommendations, they need to be at least 13 years old to benefit from those front seat technologies.

With improvements in protection for front seat occupants in newer model year vehicles, the relative improvement in protection associated with sitting in rear seats has been reduced. This phenomenon has been noted in research which shows a decreasing trend over time in the rear seat's effectiveness at reducing the likelihood of fatality.

While these data indicate needed emphasis on the rear seat, rear occupant protection has not received the same level of research attention, regulatory effort, and technological development as that of the front seat. Adapting technology advances for restraint design from the front seat to the rear seat may be a place to start; however we must first ensure those technologies are safe for the smaller and "biomechanically different" younger occupants.

To make additional significant reductions in child occupant injuries and fatalities, government and industry should work together to prioritize resources toward improvements to the rear seat. They are necessary for all rear seat occupants, including adults and the elderly, but we must pay particular attention to children as they make up the majority of those occupants. By doing so, child and youth safety advocates may achieve the biggest gains in further reducing pediatric crash injury and death.

Researchers from the Center for Injury Research and Prevention at The Children's Hospital of Philadelphia recently conducted an assessment of the current state of knowledge regarding rear seat occupant safety for adults and children. There is clear evidence, recently summarized as part of the AAP's upgraded policy statement, that use of a CRS is protective. Therefore, the assessment focused on adults and children sitting in the rear seat without using add-on restraints. This *CPS Issue Report* summarizes the information pertinent to children so that those best positioned to advance occupant protection priorities for young people can better understand the unique needs of children in the rear seat.

History of the Rear Seat

1959	Congress passes legislation requiring all automobiles to comply with certain safety standards.
1968	Lap belts required in the rear seat in the U.S.
1979	Tennessee becomes first state to require use of CRS.
1985	All 50 states require some use of appropriate CRS.
1989	Rear seat outboard lap and shoulder belts are first required in passenger cars.
1991	Rear seat outboard lap and shoulder belts are also required in convertible passenger cars, light trucks, vans and sport utility vehicles.
1995	First report of children dying in crashes due to contact with deploying front passenger air bags is published, triggering efforts to move children to the rear seat.
2000	Washington becomes first state to require booster seats for children who have outgrown their child safety seat.
2002	Anton's Law requires a performance standard for CRS for children weighing more than 50 pounds, a crash test dummy simulating a 10-year-old child, and a lap and shoulder belt assembly in all rear seating positions; it also encourages higher age limits for state CRS laws.
2004	Lap and shoulder belt assemblies required for ALL rear seating positions in a passenger motor vehicle (100 percent compliance required by 2008).
2011	Ford's inflatable rear seat belts debut in the 2011 Explorer — an early example of innovative rear seat restraint technology.
2012	NHTSA adopts use of a Hybrid III 10-year-old dummy to test child restraints recommended for children weighing more than 65 pounds.
2012	48 states require child safety seat and booster seat use to at least age 6; 17 states have rear seat requirements for children, but they vary widely.
2013	Eleven of 35 common vehicle brands offer optional or standard pretensioners or force limiting seat belts in the rear seat. Virtually all are in outboard seat positions.

Characteristics and Fatality Risks of Rear Seat Occupants

To accurately craft regulations and test procedures, it is important to understand who travels in the rear seat and how they use restraints. This information can also help us understand their risks for injury and death in motor vehicle crashes.

Who is in the rear seat?

Based on data from 2000 to 2006, approximately 13 percent of motor vehicle occupants rode in the rear seat, representing 39 billion person-trips per year. Nearly 70 percent of rear-seated occupants are children younger than 14 years of age. Most rear seat occupants (83.2 percent) are seated in the right or left outboard positions, although a majority (63.1percent) of the youngest children (less than 2 years of age) is seated in the center rear position.

How are they restrained?

An observational study of children restrained in cars in 2009 determined that most young children were restrained in a CRS: 98 percent of children less than 1 year old, 93 percent of 1- to 3-year-olds, and 55 percent of 4- to 7-year-olds. An additional 32 percent of 4- to 7-year-olds were using seat belts. Among children ages 8 to 12 years, 85 percent were in either a seat belt or a CRS. Observed restraint use among occupants age 8 years or older in the rear seat continues to be less than that of front seat occupants. However, there is an encouraging trend toward higher rear seat belt use among occupants 8 and older — from 47 percent in 2004 to 74 percent in 2010.

Risk factors for death?

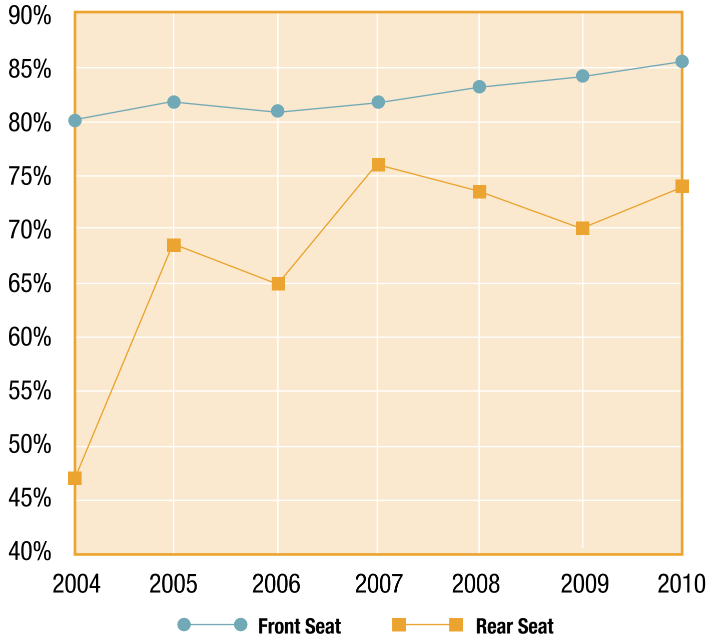
Restraint use is lower in the rear than the front seat (seat belt use for occupants 8-plus years is 74 percent in the rear vs. 85 percent in the front in 2010), with decreasing restraint use as occupant age increases. This correlates with their risk of dying in a crash.

Rear seat occupants of all ages represented 8.2 percent of all motor vehicle crash fatalities in passenger vehicles in 2010. Lack of restraint was prevalent — 57 percent of rear row occupants killed in 2010 were unrestrained, a higher proportion than in occupants who died in the front seat (46 percent unrestrained). Compared to front seat occupants, the risk of death for rear seat occupants is approximately 21 to 33 percent less. This comparative risk varies by occupant age, restraint status, presence of frontal air bags and vehicle model year.

Overall fatality risk estimates for all rear seat occupants is 7 per 1,000 occupants; but among 0- to 7-year-old rear seat occupants, it is less — 3 per 1,000 occupants — suggesting that compared to older occupants, the youngest occupants are better protected. Use of a restraint system is associated with a considerably reduced risk of death or significant injury (Abbreviated Injury Scale (AIS) of 2+ or 3+) for rear seat occupants.

For restrained occupants, as age increases, the effectiveness of the rear seat compared to the front passenger seat decreases. Data suggest that lack of advanced safety features of seat belt systems in rear seat positions may lessen the risk reduction associated with sitting in the rear seat compared to the front.

Observed Seat Belt Use: 2004 to 2010
Front vs. Rear Seat Occupants



Data Source: Pickrell T, Ye TJ. Occupant Restraint Use in 2010: Results from the National Occupant Protection Use Survey Controlled Intersection Study. Washington, DC: National Center for Statistics and Analysis, National Highway Traffic Safety Administration. 2011.

What We Can Learn from Booster Seat Design

Naturalistic studies of how children interact with seat belts and booster seats could help us design the rear seat so it is easy and comfortable for older children to remain positioned for optimal protection in a crash. A Spanish study describes restraint use among 7- to 14-year-olds in the actual driving environment. During nighttime riding, improper belt fit was noted in 78 percent of video frames sampled of children restrained by seat belts, 61 percent in those in low-back booster seats and 17 percent in those in high-back booster seats. This implies that the contours of the high back booster help keep children properly positioned.

A different study examined children solely in high-back boosters. The boosters with larger side wings were associated with lower shoulder-to-seatback contact (45 percent) due to children sitting forward to see around the side wings as compared to boosters with relatively small side wings (75 percent). Researchers suggested the protective effect of the larger side wings in side impact crashes may be negated by the increased potential for the out-of-position child's head to contact the vehicle interior in a frontal impact crash.

In a sample of 8- to 13-year-olds on trips involving a predetermined route, those in backless booster seats remained upright, corresponding to optimal mid-shoulder belt placement, approximately 90 percent of the time, while those in seat belts were upright for only 50 percent of the time. For these seat belt restrained occupants, leaning inboard to compensate for shoulder belt placement on the neck occurred 35 percent of the time.

Recommendations for Research: Occupant Factors

- Seek a better understanding of how rear seating practices of children are influenced by legislation.
- Develop and evaluate interventions to increase belt use among older children and adults.
- Collect more contemporary data on restraint practices of "tweens" (ages 9 to 13 years).
- Replicate prior analyses of the Fatality Analysis Reporting System (FARS) and National Automotive Sampling System-Crash Worthiness Data System (NASS-CDS) to estimate fatality risk for occupants by age, gender, restraint status, seating position and impact direction using more contemporary data.
- Extend collection of naturalistic data on children to a quantitative assessment.
- Evaluate the effect of these naturalistic positions observed on the potential for injury.

Mechanisms of Injury in the Rear Seat:

Vehicle components vs. restraint components

The mode by which vehicles are struck during a crash heavily influences occupants' injury risk and the types of injuries experienced. Seating position also plays a role. Crash modes are usually classified as rollover, frontal impact, right and left side impacts, and rear impact. Rollover crashes are deadliest, but frontal crashes are the most common crash mode.

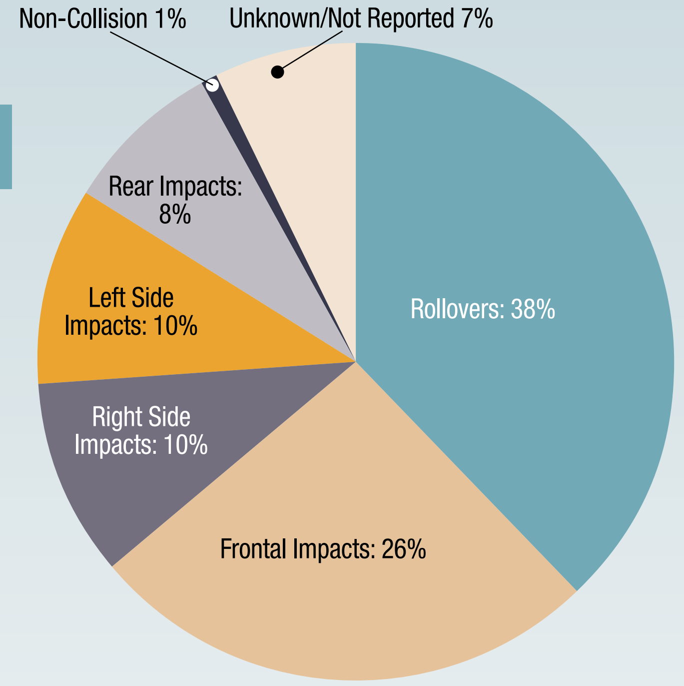
Assuming occupants are riding restrained when a crash occurs, it is important to understand, by crash mode, if their injuries were caused by vehicle components (intrusion of the side interior, impact with front seat back) or restraint components so that engineers can make appropriate decisions about safety design features.

Side impact crashes: In near-side impact crashes, intrusion and interaction with the vehicle side interior is the most significant source of injury. For rear seated pediatric occupants seated far-side to the crash, head and abdominal injuries are common. These injury patterns indicate kinematics in which the occupant's torso slips out of the seat belt, causing his head to contact structures laterally (such as the far side door panel) and slightly forward. Abdominal injuries are attributed to lateral flexion over the lap belt as the torso moves away from the shoulder belt.

Frontal crashes: In frontal crashes, among restrained rear occupants age 13 years and older with serious injuries, 76 percent of injuries were to the thorax, 9 percent to the head region, 8 percent to lower extremities, and 5 percent to the abdominal region. Ninety-five percent of thoracic injuries are attributable to the seat belt.

Injury patterns are different for younger children, likely due to the biomechanical differences between children and adults. For those child occupants restrained in frontal crashes, head injuries predominate, with most injuries due to contact with the seatback in front of them and the side interior.

Crash Modes That Result in Rear Seat Fatalities



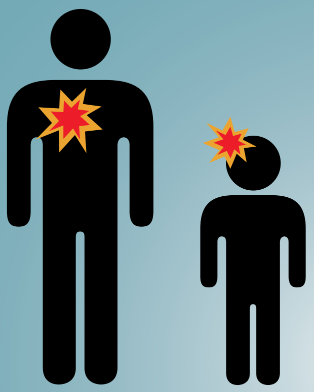
Among rear seat occupant deaths for age 15 and under in FARS in 2011

Data Source: Fatality Analysis Reporting System (FARS), National Highway Traffic Safety Administration.

Injury Patterns Vary by Age in Frontal Crashes

Adults and Teens: chest injuries due to seat belt loading

Children: head injuries due to contact with vehicle interior



No Need to Reinvent the Wheel

Advanced technologies already developed to make the front seat safer provide obvious opportunities as starting points for improvements for rear seat occupants. Sled tests and computer modeling suggest that adopting seat belt features such as load limiters and belt pretensioners (defined below) can substantially reduce the risk of serious (AIS3+) head and chest injury among rear seated occupants.

However, there may be a trade-off to consider. **Safety belt load limiters** reduce chest injuries but increase head excursion. **Safety belt pretensioners** can reduce head excursion; but if they pull with too much force, they can increase chest injuries. In the front seat, this trade-off is managed by load-sharing air bags and knee bolsters. In addition, assessing this trade-off may be different across the range of occupants restrained by a seat belt in the rear seat — pre-teens to elderly females.

In a computational modeling study of children in booster seats, simulations revealed that the combination of shoulder belt load limiting and lap belt buckle pretensioning actually improved chest and abdominal injury metrics while reducing head excursion. This finding indicates that these technologies may provide injury reduction potential for pediatric rear seat occupants.

Laboratory tests of the effectiveness of air bags on reducing injury risk to rear seat occupants suggest that **side air bags** can reduce the risk of severe thoracic injury from 36 percent to 3 percent in a side impact crash for adult occupants.

A **head curtain air bag**, which in addition to providing protection in side impact crashes, stays inflated longer to prevent ejection in a rollover crash. In a study of front-seated adult occupants, researchers found that such technology was responsible for a 29 percent reduction in AIS2+ injuries as compared to occupants in vehicles with less side impact protection (including structural improvements and a torso side air bag, but no curtain air bag). There is no research that suggests curtain air bags pose a risk to children.

Laboratory evaluation of **inflatable seat belts**, offered on some passenger vehicles beginning in 2011, suggests they can reduce the likelihood of severe head and neck injury by providing support to the occupant's head and reducing

Definitions of Advanced Occupant Restraint Technologies

Safety belt pretensioners pre-emptively tighten the belt to remove the slack in the belt immediately prior to impact. They are triggered by sensors in the vehicle. They also prevent the occupant from submarining, or slipping under, a loose belt in a crash.

Safety belt load limiters release excess belt webbing when a certain level of force is applied to the belt to minimize belt-inflicted injury in a crash. The simplest load limiter is a "fold" sewn into the belt webbing. The stitches are designed to break when a certain amount of force is applied to the belt, allowing the webbing to unfold and the belt to extend a little bit more.

Inflatable safety belts have inflatable tubes contained within an outer covering. In a crash, the tubes inflate with a cold compressed gas to increase the area of the restraint contacting the occupant, spreading crash forces. These belts also tighten the belt around the occupant.

Seat Belt Pretensioners:

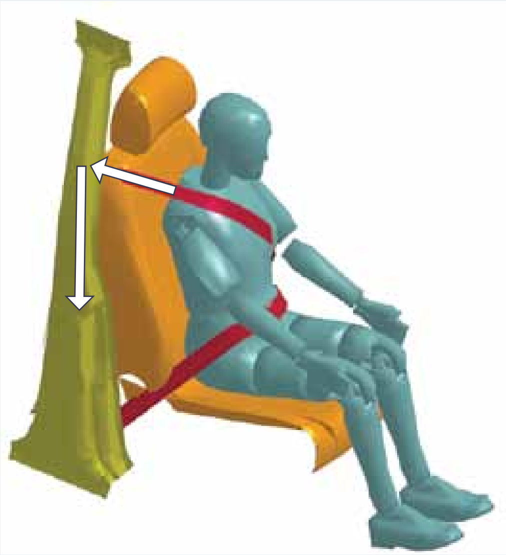
Pretensioners help optimize the performance of the restraint system by removing slack in the seat belt before the occupant substantially begins to load the restraint. Minimizing the slack increases the likelihood that the seat belt will apply load to the desired boney portions of the body — the pelvis and the clavicle — for an appropriately sized occupant.

the amount of rotation and neck flexion and extension experienced during a crash.

The geometry of the actual seating configuration is an additional important aspect of rear seat restraint as it can affect how an occupant positions herself on the seat and how the belt lies across her. Today, **rear seat geometry** is incompatible with most of the occupants who sit there.

One measure of this is seat cushion length, which is much longer than needed for optimal restraint and comfort. Previous research showed the median second row seat cushion length of 455 mm was longer than the thigh length of 24 percent of adults and 83 percent of children. As a result, an occupant will be forced to slide forward on the seat so his knees bend comfortably at the seat cushion edge. This raises the lap belt high on the abdomen and often places the shoulder belt in an uncomfortable position.

Evaluation of rear seat shoulder belt anchorages (where the shoulder belt is attached to the vehicle above or behind the occupant) found that only 35 to 55 percent of shoulder belts cross the intended mid-clavicle region for an average 8- to 15-year-old.



Recommendations for Research: Technology

- Evaluate the benefits of a package of advanced restraint technologies and improved seat geometry on rear seat occupant kinematics and injury risk in a real vehicle environment.
- Quantify the benefit of curtain air bags to rear seat occupants, especially children.
- Assess the performance of rear seat restraints in the context of potential contact with other vehicle interior structures (e.g., seat back in front, side interior).
- Evaluate the potential of an in-vehicle restraint system to provide protection to a range of rear seat occupants from the 6-year-old anthropomorphic test device (ATD) to the 50 percentile adult male ATD.
- Conduct laboratory and real-world evaluations of vehicle-based restraint systems that are customizable to the size of older children through adults.
- Determine the effectiveness of rear seat belt reminder systems to increase belt use.

Recommendations for Policy

- Ensure implementation of advanced seat belt technology in the rear seat in order to reduce injuries commonly seen in frontal impact crashes for rear seat occupants.
- Assure test procedures minimize rear occupant injury due to intrusion in side impact crashes.
- Develop regulatory procedures in frontal crashes in which the potential for vehicle interior contact by rear seat occupants can be evaluated.

Don't Leave the Rear Seat BEHIND

Prioritizing for Child Passengers

The primary occupants of the rear seat of passenger vehicles are children. In fact, 70 percent of rear seat occupants are children younger than 14 years. Children under age 16 spend nearly as much time in motor vehicles as adults, averaging 3.4 trips per day and 45 to 50 minutes in duration. Today's kids spend more time being transported in passenger vehicles than previous generations and merit equal consideration when enhancing vehicle safety for occupants.

Even though vehicles and occupant behaviors have generally become safer and fewer children are dying in crashes than a decade ago, there is still an unacceptable number of our young dying in crashes — 952 deaths among children ages 15 and younger in 2010.

There is great opportunity for the United States to further reduce child occupant injury and death by focusing on rear seat safety design. Based on our review of data and available research, experts from The Children's Hospital of Philadelphia's Center for Injury Research and Prevention recommend the following prioritization for policymakers within government and industry.

Get rear seat occupants restrained appropriately for their age and size.

To do this:

- Explore effectiveness of rear seat belt reminder systems.
- Explore effectiveness of interventions designed to increase rear seat vehicle belt use for tweens, teens and adults.
- Close gaps in state laws to mandate restraint use for all occupants, including rear seat occupants, with primary enforcement.

Bring advanced restraint design to the rear seat.

To do this:

- Develop regulatory procedures or vehicle performance programs for consumers that dynamically evaluate the protection of rear seat occupants including the likelihood of contact with the vehicle structures in front of them.
- Develop engineering strategies to reduce rear occupant injury due to intrusion in side impacts.
- Incorporate improvements in rear seat geometry along with advancements in restraint design.

Conduct immediate research to inform these priorities.

To do this:

- Design and evaluate customizable vehicle restraints that can provide protection to the 6-year-old ATD, 10-year-old ATD and 50th percentile male ATD.
- Collect contemporary data on rear seat restraint practices and injury risk in the current fleet and current child occupants.
- Determine how children's posture and position in restraints, as observed in a naturalistic setting, affect injury risk.

Sources

The initial research behind this CPS Issue Report *involved extensive review of scientific literature. The following databases were queried to answer our questions: Scopus PubMed, Institute for Scientific Information (ISI) Web of Knowledge, Society of Automobile Engineers (SAE) Global Mobility Database, ESV Conference Proceedings abstracts (from 2003, 2005, 2007, 2009 and 2011), and publically available online NHTSA reports. All searches were limited to work published since 2001.*

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