Child Occupant Protection: Latest Knowledge and Future Opportunities – Results of a Workshop in Gothenburg, Sweden

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INTRODUCTION

In 2010, road traffic injuries accounted for approximately 1.24 million deaths; 31% which were motor vehicle occupants. Children 0-14 years represent anywhere from 5-13% of all road traffic deaths depending on the income level of the country (Global Status Report on Road Safety, WHO, 2013). (Figure 1) Road traffic injuries are the leading cause of death among young people aged 15 to 19 years and the second leading cause of death for 5-14 year olds. Looking beyond fatalities, the number of children injured or disabled each year as a result of road traffic crashes has been estimated at approximately 10 million. While reductions in fatalities and serious injuries have been achieved, prevention of fatalities and injuries from motor vehicle crashes remain a public health priority for the safety of children and adolescents.

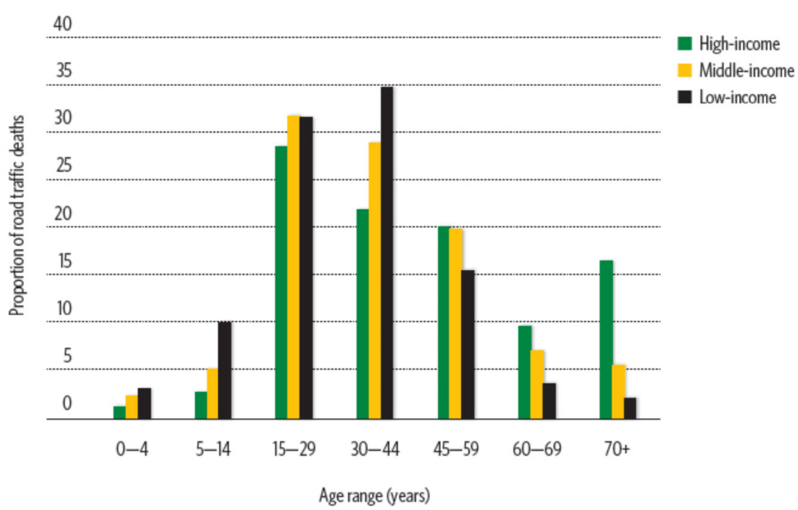

Figure 1: Proportion of road traffic deaths by age group and country income status. Reproduced from the WHO Global Status Report on Road Safety, 2013.

Child occupant protection remains a focus for a diverse set of stakeholders. To facilitate international coordination and sharing of knowledge around this topic, a workshop was previously convened in 2011 bringing together international leaders in the fields of child occupant protection, biomechanics, and auto safety to review critically the state-of-knowledge in the field, translate the Decade of Action for Road Safety framework to child-specific priorities, and identify high-priority research topics and strategize toward their implementation. A summary of this workshop was presented at the 2011 Protection of Children of Cars Conference. Briefly, the following key themes were identified:

- A deliberate emphasis needs to be placed not only on reducing fatalities but also reducing injuries with a particular focus on disabling injuries, short term and long term morbidity and recognizing the impact of a child's health on their family
- Research and policy priorities should follow a Research to Action to Impact model in which the steps are:

Surveillance	• Contain child specific data • Be contemporary • Provide country-specific data
Identification of issues in need of further study	• Based on rigorous epidemiological analyses that quantify distribution and determinants of injury
In-depth study	• Multi-disciplinary – behavioral science, biomechanics, crashworthiness, public health and epidemiology • Focus on traumatic brain injuries of all severities
Dissemination/publish	• Targets include researchers, governments, industry, community leaders, and lay public • Become skilled at alternative research dissemination tools, such as web pages and social media • Understand marketing and other methods for behavior change • Ensure the traffic safety story is being heard
Implement interventions	• Educational tools, improved product design and improved legislative and regulatory policy
Measure impact	• Relies on surveillance systems being in place • Effectiveness (real-word) vs. Efficacy (experimentally controlled)

In order to ensure attention remains focused on the topic of child occupant protection, this working group of leaders in child occupant protection, biomechanics and auto safety reconvened in September 2013 in Goteborg, Sweden. The focus of the 2013 meeting was to:

1) Review and update the research and regulatory agenda for child safety.
2) Identify areas of collaboration
3) Facilitate actions towards this agenda in the different spheres of influence of the participants

The following describes the recommendations that emanated from the meeting.

PROCESS

A two day workshop was held in which the first day was composed of presentations on relevant topics. The focus of these presentations was on 'pressing issues in child and adolescent occupant protection' – including short and long term research, policy and regulatory issues as well as global priorities. The second day was a guided discussion focused on prioritizing the topics raised in the first day of presentations. This effort included 17 individuals representing diverse organizations and scientific disciplines:

- Behavioral scientists
- Biomechanists

- Epidemiologists
- Government researchers
- Physicians
- Auto safety researchers
- Restraint suppliers
- Vehicle manufacturers

A list of specific attendees is contained in the Appendix.

KEY PRIORITIES IDENTIFIED

Eight research priorities were identified and below is summarized the key characteristics desired of these efforts. They are listed below, in no order of importance.

1. Prioritize head injury mitigation in the rear rows via restraints that prevent head impact, or via safety technologies that better manage head impact energy.

Traumatic brain injury (TBI) continues to be a major health epidemic, with an annual incidence in the United States in excess of 1.5 million per year, leading to 50,000 fatalities and 3.7 million people living with long-term disability from TBI (Rutland-Brown et al. 2006). These numbers include both severe forms of TBI as well as the more common mild TBI or concussion. Worldwide, the incidence of TBI has been estimated at 500 million new cases annually (circa 1985), and due to increasing global automobile use and declining deaths due to infectious diseases, TBI is becoming the global dominant source of mortality and morbidity (Kraus et al. 1996). TBI is particularly devastating to the young. Hospitalization costs associated with pediatric TBI are estimated to exceed $1 billion annually (Schneier et al. 2006), and post-TBI neuropsychological sequelae include altered behavior and diminished academic achievement, increased family strain and burden of care, and quality of life similar to pediatric oncology patients, all extending for years following the injury event (Rivara et al. 1996; Taylor et al. 2002; Yeates et al. 2002; Anderson et al. 2005; McCarthy et al. 2006; Wade et al. 2006; Aitken et al. 2009).

In countries around the globe, traumatic brain and skull injuries are the most common serious injuries sustained by children in motor vehicle crashes, both as vehicle occupants and pedestrians (Jorgensen 1995; Arbogast et al. 2002; Durbin et al. 2003; Howard et al. 2003; Orzechowski et al. 2003; Arbogast et al. 2004; Yao et al. 2007; Wu et al. 2008). As the risk of head injury in motor vehicle occupants increases with increasing child age (Arbogast et al. 2002), there is need to develop TBI mitigation strategies that protect the child that has outgrown the add-on child restraint. These mitigation strategies should focus on the rear rows, since most children sit there, and strategies should include comprehensive efforts to reduce incidence of head contact, and management of the impact energy when head contact occurs.

Decreasing the frequency of brain injuries can be achieved by incentivizing safety system design improvements in the rear rows; consumer information programs (eg. USNCAP, IIHS, EuroNCAP) have proven effective in the enhancement of front seat safety, and some are already creating incentives for the rear rows (see research priority #8 below). Research is needed in several areas to provide better computational models (#3), develop accurate injury criteria (#2), and investigate realistic occupant seating positions (#4).

2. Quantify the fundamental mechanics of children in impact-relevant loading conditions including materials and structure.

The developmental processes that occur with aging from birth to young adulthood cause a complex range of changes in the structure of the human body. These changes occur at length scales ranging from sub-millimeter (for example, proteoglycan content within articular cartilage) to meter (for example, the angle of the spinal facet joints and the shape of the iliac wings). Over some length scales, these changes manifest as developmentally dependent continuum-level material properties, such as the failure strain of cortical bone, and at other length scales they manifest as structural properties that dictate the manner in which externally applied loads are distributed throughout the body.

Fundamental knowledge of pediatric development is lacking over the entire range of those length scales. Samples of pediatric tissue have been characterized and compared to adult tissue for decades, and this type of research has increased in recent years as tests on samples of cortical bone, hyaline cartilage, abdominal organs, and other tissues have been reported (Crandall et al., 2013), but the range of what is known even at the material level is dwarfed by what remains unknown. Knowledge of the whole-body response of children in potentially injurious impact loading situations remains essentially undefined. Such data are critical for determining the loads to which organ-level materials are exposed during the complex external loading environment of a car crash. Therefore, while recent advances that define material-level behavior have been useful for quantifying the risk of failure when a material is loaded, further research must quantify the relationship between whole-body dynamics and loads to internal tissues in order to maximize the utility of pediatric tissue material property data.

3. Develop biomechanical research tools specific for children

The primary tools by which the automotive industry and engineering research community evaluate occupant protection are anthropomorphic test devices (ATD) and computational models of those ATD. The effectiveness of these efforts is directly related to how well the ATD mimic actual humans in their kinematics and injury prediction ability. Pediatric ATD have largely been size scaled versions of adult ATD as pediatric-specific biomechanical data have been lacking. In the last 10 years, there has been an increase in fundamental biomechanics data that quantify the child and adolescent's component level response to dynamic loading (see above) (for a comprehensive summary see Crandall et al, 2013). It is critical that these data be incorporated into ATD design in a timely manner.

As is the case in all areas of engineering design and evaluation, computational assessment of occupant protection is gaining in importance and value. Computational models of the ATD – which are, for the most part, exact replicas of the physical ATD, were initially introduced to fill this need. Construction and the need for durability and repeatability however places limits on how biofidelic the ATD can be. To address this gap, computational human body models were introduced. These models allow for detailed representation of human anatomical structure and materials. For example, these models can use radiology to define the geometry of the liver and model that structure with material properties measured in component level tests. The human body model is then assembled with each of these anatomic pieces to represent a virtual human.

There has been tremendous effort to develop these models for adults, most notably through the Global Human Body Modeling Consortium (www.ghbmc.com), the development of THUMS (Total Human Model for Safety) and initiatives within the EU child safety project CASPER. Although pediatric human body models are part of these efforts, the workshop attendees wanted to emphasize that pediatric model development is critical for advancing the safety of children and adolescents in motor vehicles and to urge GHBMC and other organizations that develop such models to ensure that child-specific models remain a priority. Furthermore, the field is benefitted by harmonization of these models rather than having, for example, several human body models simulating a 10 year old child. Integration of these efforts and knowledge into a single model is not trivial and presents logistical challenges but in the end is the most resource efficient approach. Lastly, it is important that these models have the capability to be modified parametrically to account for natural variations in anthropometry, structural geometry and material properties.

4. Define realistic postures and positions child occupants assume and quantify the effects of these postures on injury risk. Assess the behavioral factors that lead to sub-optimal positions.

Restraint performance is evaluated using anthropomorphic test devices (ATD) positioned in prescribed, optimal seating positions. Human occupants, children in particular, have been observed to assume a variety of additional positions that involve changes in posture and alterations in seat belt placement and geometry which are assumed to potentially affect restraint system performance (van Rooij et al. 2005, Andersson et al. 2010, Charlton et al. 2010, Jakobsson et al. 2011, Osvalder et al. 2013).

There have been several efforts to describe these position and postural differences using naturalistic, observational methods. These methods typically involve a parent driving an instrumented vehicle with no special instructions, no experimenter present, and data collection via unobtrusive instrumentation. Initially these efforts, while being critically important for defining the nature and magnitude of the problem, have been largely qualitative and/or dichotomize the out-of-position as present or not (i.e. leaning forward out of the restraint as a yes/no variable). More recent studies are underway that use emerging technology to quantify these positions and postures (see Charlton et al, 2013 Protection of Children in Cars conference) as well as identify important driver and occupant behaviors that lead to such sub-optimal positioning.

Ultimately, however, it is important to understand if these positions correlate to increases in injury risk by simulating some of the common seating postures in crash tests with pediatric ATDs or human models and quantify changes in injury metrics. From this work, recommendations will be able to be made for improving test protocols, in particular ATD positioning, so that laboratory assessment of occupant protection more accurately evaluates safety in realistic occupant conditions. In parallel, the ATDs and human models need to be validated for such situations.

5. Establish collaboration with countries that are rapidly becoming motorized to ensure adequate exchange of information about ongoing activities to prevent pediatric occupant injuries in that country.

As countries such as China, Brazil and India strengthen their economic foundations, their people are becoming rapidly motorized and children are increasingly being transported in motor vehicles.

These markets should not have to progress at the same pace through the stages of child occupant protection that countries/regions such as the US, Europe and Australia have gone through over the last 50 years– from unrestrained children in the laps of caregivers to lap only seat belts worn by toddlers to advanced child restraints with dedicated attachment systems in the rear seats of vehicles. Mechanisms must be created that allow for the sharing of child traffic safety knowledge within the context of each country's specific needs.

Experienced researchers in the field of child safety first must improve their own understanding of the child safety activities of these countries and identify the potential contributions of previous research from the US, Europe, Australia and Canada. This should include developing an understanding of the country-specific data collection systems, how this data is used to support policy and the effective channels for public education. The context of child safety legislation and its enforcement is of importance to study. From the Global Road Safety Report Card in 2013, only 25% of high-income countries and 5% of middle income countries have child safety laws accompanied by good enforcement (Figure 2). Lastly, data from the World Health Organization suggest that the focus of child road traffic injury prevention in these rapidly motorizing countries must be inclusive of other vulnerable road users beyond child occupants. Moving children into vehicles as occupants likely makes them safer than other forms of transport on a per-trip and per-mile basis. In many of these countries, however, the very small vehicles that are being adopted due to space, cost, and sustainability concerns pose challenges for the installation of child restraints thus indicating that their solutions may vary from those previously developed for other regions.

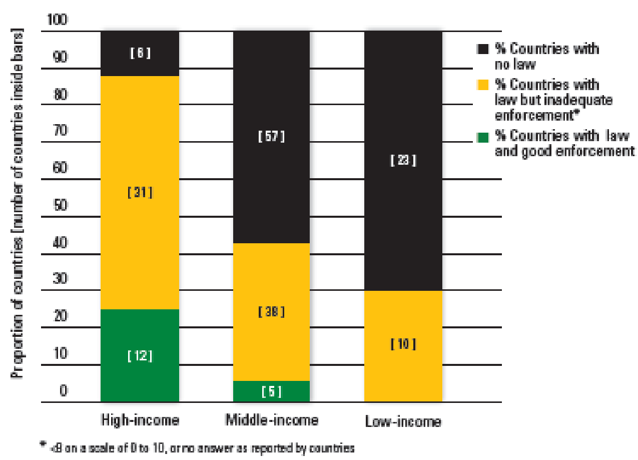

Figure 2: Child restraint laws and enforcement. Reproduced from the WHO Global Status Report on Road Safety, 2013.

6. Continue crash injury surveillance specific to children in a way that is nationally or regionally representative

Effective surveillance is based on high-quality data systems. Specifically, such systems need to ensure that high quality child-focused data will be collected on a sufficient number of children and adolescents to be representative of the geographic area of study and support pediatric-specific activities of research, policy and education. There is compelling evidence that such data are critical for continued advancements in occupant protection for this age group.

The level of detail is dictated by the locality of focus. For example, in Sweden, due to their low numbers of child and adolescent fatalities, a very detailed level of crash surveillance is necessary that systematically describes the interaction between restraint use, crash dynamics and injury outcomes in order to further reduce their injury and fatality burden. In contrast, in countries with emerging economies and motorization, simply knowing how many children are involved in motor vehicle crashes, where they are seated and how they are restrained would be valuable surveillance data upon which to base policy.

7. Adapt the Abbreviated Injury Scale (AIS) to include varied outcomes such as long-term disability and cost. Quantify the influence of age on the interpretation of specific injury codes.

The Abbreviated Injury Scale (AIS) was originally created by the Association for the Advancement of Automotive Medicine (AAAM) as a threat-to-life scale and has been used as a standardized benchmark of injury severity. As motor vehicle crash-related deaths are decreasing in high-income countries, particularly for children, there is an increased need to understand the non-fatal burden of injuries including functional disability (physical, cognitive, behavioral) and quality of life. In addition, it is also critical to measure the cost of fatal and non-fatal injuries to society including acute and chronic medical care expenses, wage and productivity losses, and reduced quality of life costs. Since pediatric occupants differ from adults (and children of various ages differ from each other) in terms of injury tolerance and recovery, age-specific differences in injury risk and outcomes should be further quantified and systematically categorized. Incorporating disability outcomes, cost, and age-specific measures into the AIS can further enrich this ubiquitous and long-standing tool for injury severity, which will benefit injury prevention (through more informed injury risk curves) and treatment (through improved injury triage, pre-hospital and acute care, and rehabilitation).

8. Stimulate development of engineering strategies for occupant protection in the rear seat through inclusion of seat belt restrained rear occupants in consumer rating programs. Emphasis on vehicle design improvements targeted to children should be highlighted.

Both regulation and consumer ratings programs can accelerate diffusion of advanced occupant-protection technology into the marketplace. A contemporary example is the rapid introduction of countermeasures in vehicles to address structural performance issues highlighted in IIHS recent small overlap rating tests (http://www.iihs.org/news/rss/pr051613.html). One reason for the lack of advanced restraints in the rear seat is the limited regulation and ratings programs targeted to these seat positions. We recognize that vehicle manufacturers have many competing priorities in addition to safety such as fuel economy and cost. The absence of such a rating program does not allow rear seat occupant protection to keep pace with advances in front seat protection leading to ongoing reductions in front seat injury risk observed in recent data. Several of the front seat restraint technologies, such as seat belt pretensioners, seat belt load limiters and side airbags, are becoming available in the rear seat however wider market penetration is needed in order to provide substantial real world benefits.

Country-specific consumer information programs (NCAPs) should prioritize the rear seat evaluation of occupant protection for children and adolescents as they represent the majority of the occupants in the rear seat. Approximately two-thirds of rear seat occupants in crashes are children less than 15 years old (Children's Hospital of Philadelphia, 2013) and 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 (Santos et al., 2011). Inclusion of ATDs that represent younger occupants utilizing the vehicle restraint system in these rating programs will facilitate the introduction of novel restraints and seat structures that improve protection for youth.

CONCLUSIONS

The panel of experts convened for the Gothenburg workshop identified that further advances in child road traffic injury protection will require rigorous collaborative research and policy development by multiple disciplines and global organizations that consider the unique needs of children. Central to success in these efforts is a common platform of priorities. This manuscript lays out specific activities that can serve as a blueprint for researchers worldwide. In addition to the in-depth research priorities, the panel emphasized the importance of country-specific surveillance to help set specific research emphases for those localities. Linkages and information exchange with rapidly motorizing countries are critical in order to address the global burden of road traffic for children and youth.

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WORKSHOP ATTENDEES

Specific attendees of the workshop are listed below. All contributed greatly to the discussion at the workshop and the formation of the concepts described in this manuscript.

- Kristy Arbogast, PhD – Children's Hospital of Philadelphia, University of Pennsylvania
- Katarina Bohman, PhD – Autoliv Research, SAFER
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- Suzanne Tylko, BSN - Transport Canada
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