Child Occupant Protection: Latest Knowledge and Future Opportunities – Results of a 2015 Workshop in Gothenburg, Sweden

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INTRODUCTION

Child occupant protection research remains a critical need for industry, academia, government and safety advocacy organizations. While reductions in fatalities and serious injuries have been achieved, motor vehicle crashes remain a leading cause of death and disability for children and adolescents and as a result, represent a public health priority.

To facilitate international coordination and sharing of knowledge around this topic, the fourth biennial international workshop on Child Occupant Protection was convened in September 2015, bringing together worldwide leaders in the fields of child occupant protection, biomechanics, and auto safety to critically review the state-of-knowledge in the field and identify high-priority research topics and strategize toward their implementation.

Summaries of previous workshops were presented at the 2011 and 2013 Protection of Children in Cars Conferences. The following describes the recommendations that emanated from the 2015 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. As part of this effort, the research priorities identified from the 2013 workshop were reviewed and confirmed as ongoing areas of focus. A review of progress in each area revealed specific activities of research and application.

During the second day, we identified 5 important questions in need of thorough discussion from a variety of stakeholders. The questions and initial thoughts of the workshop attendees are summarized below.

1. There has been tremendous recent advancement in computerized child models and fundamental pediatric biomechanics data. Their utilization and acceptance is limited. What strategies should be used to accelerate use and application of the models and data to realize tangible benefits to child occupants?
2. Child occupant protection is currently complex for families. How do we help families make the right choice – how do we make typical behavior safe? How do we simplify the use of safety technology?
3. Our field primarily focuses on fatalities and more serious injuries. How should we also consider less severe injuries? Can our current tools discern acute injuries with low fatality risk that may have long term consequences?
4. Countries such as China and India are becoming rapidly motorized. How do we ensure adequate data collection to address specific needs in these settings? What education or innovative technology is needed to increase usage of age-appropriate restraints for different specific cultural context?
5. Our goals are to promote introduction of novel restraint designs, to confirm restraints have no unintended consequences for children, and to ensure all designs follow fundamental biomechanical principles. How do we ensure existing and emerging restraints are fully evaluated in diverse loading conditions for *"real kids" in "real cars"*?

This effort included 18 individuals from diverse organizations and scientific disciplines:

- Behavioral scientists
- Biomechanists
- Epidemiologists
- Government researchers
- Physicians
- Auto safety researchers
- Restraint suppliers
- Vehicle manufacturers
- Test centers and rating institutions

A list of attendees is contained in the Appendix.

REVIEW OF PROGRESS AND ACTIVITIES ON KEY PRIORITIES

Eight research priorities were identified at the 2013 workshop (Arbogast et al., 2013). Selected accomplishments and activities since 2013 in each area are described below.

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.

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 Traumatic Brain Injury (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.

<u>Selected accomplishments since 2013</u>: There has been tremendous focus on understanding the mechanisms of mild traumatic brain injury or concussion primarily through the instrumentation of youth athletes with head impact sensors and relating the biomechanics of impacts sustained on the athletic field to clinical outcomes of brain injury (e.g. Rowson et al., 2009; Crisco et al., 2011; Broglio et al., 2010). These methods are not without limitation: the sensors systems have low accuracy (Allison et al., 2014; Allison et al., 2015) and the diagnosis of concussion remains subjective and subject to under-reporting (McCrea et al., 2004). Despite these limitations, this approach shows promise and understanding how to translate mechanistic knowledge from the athletic field to the automotive environment is important.

It has long been recognized that rotational mechanisms are part of the causal pathway of traumatic brain injury. However, current means by which to assess head injury protection were limited to linear measures of head acceleration primarily in the form of the Head Injury Criterion. A new metric has been introduced – the Brain Injury Criterion (BrIC) – which is based on head angular velocity measures (Takhounts et al., 2013). To date, this metric has not been scaled to pediatric sized occupants but represents an innovation in how to assess the head injury mitigation potential of vehicle and restraint design advances. Future work is needed to extend this development to children.

EuroNCAP has begun to address head injury mitigation in rear rows with the introduction of their 2016 test procedures. Pediatric protection will be assessed through the use of the Q6 and Q10 ATDs in the rear rows for both frontal offset deformable barrier tests and side mobile deformable barrier tests. Several head injury measures will be used in the scoring including head excursion (frontal tests only), HIC15, and head acceleration (linear). Of all the body regions assessed, the head represents the one with the potential for the most points in the scoring scheme further emphasizing the importance of head/brain protection.

An innovative restraint design was proposed by Lopez-Valdes and colleagues (2013a, 2013b). In order to prevent sub-optimal head positions (either forward or lateral leaning due to sleeping or voluntary activity), a flexible head support system was designed and evaluated that impedes extreme lateral bending and flexion motions of the head. A naturalistic driving study with 30 sleeping volunteers showed reduced lateral excursion, improved belt fit and a reduction in the frequency of slouched positions of the children.

Other advances that have the potential to improve head injury mitigation have been accelerated through the development of improved computational models (#3) and the investigation of realistic occupant seating positions (#4).

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

Understanding the unique biomechanical response of the child is challenging, as compared to the wealth of biomechanical data on the adult response to trauma, pediatric biomechanical data are relatively sparse. As a result, quantitative scaling relationships based on anatomical and material differences have been historically used to understand the biomechanics of the child. The last decade, however, has seen a tremendous increase in contributions to the biomechanics literature based upon pediatric subjects – volunteers, post-mortem human subjects, and animal models – thus increasing our knowledge of how to design injury mitigation systems to protect the young.

<u>Selected Accomplishments since 2013</u>: This body of literature has been recently summarized (Crandall et al., 2013; Yogandandan, Nahum and Melvin, 2014). The challenge ahead lies in integrating this new biomechanical knowledge into the tools used by the automotive industry to design vehicles and restraints – including pediatric ATDs and computational models (see #3 priority below).

3. Develop biomechanical research tools specific for children

The primary tools by which the automotive industry and the engineering research community evaluate occupant protection are ATDs and computational models. The evolution of computational models encompasses computational versions of the ATD as well as human body models. The effectiveness of these efforts is directly related to how well these tools mimic actual humans in their kinematics and injury prediction ability.

<u>Selected accomplishments since 2013</u>: Human body models (HBM) are becoming more advanced than ATDs (matching better the known human response) since their structure is not limited by the durability and construction limitations that restrict the physical ATDs (and therefore their computational analogs).

In recent years, numerical HBMs have become increasingly popular to simulate both pre-crash and in-crash occupant responses. Published child HBMs have been developed for crash scenarios and the limited validation has focused only on crash loading (Brolin et al., 2014). To extend to the pre-crash environment, Brolin et al. (2015) developed, validated, and applied a 6 year-old HBM with active muscles (active HBM) to study pre-crash steering maneuvers. This work illustrates the potential that active HBMs have to design and assess future child safety systems. While this model was validated for pre-crash maneuvers, more work remains as the model lacks validation for crash loading and has severe limitations in the ability to predict injury, as it is a multi-body model.

Another area of advancement has been in the development of finite element (FE) HBMs which have the potential to predict injury risk and may be better suited to the needs of the automotive industry. A recent review (Brolin et al., 2014) of child HBMs concludes that the only available FE models with age dependent anthropometry details were a 3 year-old HBM (Zhang et al., 2009) and a 10-year-old HBM (Shen et al., 2015). The 10 year-old HBM is currently available through an academic license. The ongoing European project PIPER (http://www.piper-project.eu/) intends to release improved child HBMs with an open source license in a few years. These models are based on child anthropometry and will be scalable to represent children from approximately 1 – 12 years of age. (Beillas et al., 2013, 2014a, 2014b)

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).

Selected accomplishments since 2013: There have been several efforts to describe these position and postural differences using naturalistic, observational methods. Osvalder et al. (2013) described differences in seating posture, behavior and comfort for children 7-9 years of age seated in an integrated booster cushion versus a high-back booster seat during an on-road drive. In the high-back booster seat, the children spent less time seated with the upper back and shoulders in contact with the backrest and several children were not able to sit comfortably within the side supports. This was especially true for children using electronic handheld devices. The individual variation in seated posture among children on the high-back booster seat was greater compared to children on the integrated booster cushion.

Charlton and colleagues from the US and Sweden are leading a large naturalistic driving study where all study participants are families with children who are rear row occupants (Charlton et al., 2013). Two study vehicles were equipped with video cameras, recording systems, and data acquisition units. Data collection on 43 families with 80 child occupants is now complete. 1,659 trips with 690 hours of observational data has been collected. The investigators are currently investigating the feasibility of automated solutions to automatically 'flag' incorrect/sub-optimal positions events throughout driving trips including the novel use of the Kinect motion tracking system to quantify the position of the head throughout the trip (Arbogast et al., 2013). Results from these analyses are forthcoming in the upcoming year.

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. Klinich et al. (2014) conducted sled testing with the 6YO and 10YO Hybrid-III ATDs to assess the effects of realistic seat cushion length and belt anchorage locations on outcomes in simulated frontal crashes. The ATD positioning procedure, which is based on actual child occupant postures measured in previous studies (Reed et al. 2011). The sled test results showed that shorter seat cushions and more-upright lap belt angles are associated with better kinematics for these ATDs.

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.

Selected accomplishments since 2013:
Primarily motivated by the discussions of the workshop in 2013, workshop leaders led the creation of the International Conference on Child Car Safety Technology – first held in Shanghai, China in October 2014. Hosted by the Shanghai Motor Vehicle Inspection Center, the conference was well attended by industry, government and other stakeholders in child passenger safety in China. The goal of this education exchange was to share the experience of road traffic safety for children from Europe and the US with attendees, as their country rapidly motorizes and their children become at risk. The statistics are sobering – an estimated 18,000 children 0-14 years of age in China die every year on the roads and child restraint use for 0-4 year-olds was reported to be around 4% in Shanghai in October 2014.

Several key advancements have recently happened in China. Shanghai passed a child restraint law in 2014 (followed by some additional regions) requiring children under 4 years of age to be restrained in a child safety seat and nationally, child restraints are now required to pass a certification test that mimics ECE R44.The law also requires children of 12 years or younger to be seated in the rear seat. These activities can only lead to improvements in child safety. At the Second Annual International Conference on Child Car Safety Technology held in October 2015 in Shanghai, two different observational studies reported child restraint use at 11% and 19% indicating progress but large opportunities for improvement.

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.

Selected accomplishments since 2013: Due in part to the Decade of Action, there has been increased attention to road traffic injury surveillance for all road users, including children. The World Health Organization summarized much of those efforts in the Global Status report on Road Safety, released in October 2015. Several highlights from that report include:

- Only 52 countries have a child restraint law for occupants of vehicles based on age, height or weight, and apply an age or height restriction on children sitting in the front seat
- Some vehicles sold in 80% of all countries worldwide fail to meet basic safety standards, particularly in low- and middle-income countries

Actions worldwide towards the Decade of Action fatality and injury reduction targets were reviewed at the 2nd Global High-Level Conference on Road Safety that was held in Brazil in November 2015. An example of advancement in this area includes the fact that children are now included in the China In-Depth Accident Database (CIDAS) and similar data collection systems in India (RASSI).

In the US, a recent analysis provided prevalence estimates for rear seating and restraint use by age group, as well as estimates of injury risk for restrained rear row occupants by age and impact direction (Durbin et al., 2015). This effort also provided estimates of reduction in risk of death for rear versus front occupants by age group and vehicle model year. These findings represent the most recent comprehensive look at the crash injury picture for children in the US and highlighted the limitations of the current child-specific crash surveillance system for highly developed countries like the US.

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. Incorporating disability outcomes, cost, and age-specific measures into the AIS can further enrich this ubiquitous and long-standing tool for injury severity.

Selected accomplishments since 2013: While a new scale that incorporates age-specific measures or metrics of disability has not yet been developed, the fundamental research towards this end has been initiated. Several key findings are as follows:

- When using admitted maximum abbreviated injury scale thresholds (MAIS) of 3+ or MAIS 2+ for road traffic injury patients, 54% and 80% of all disability adjusted life years are captured, respectively. This information can help to more granularly inform the definition of serious road traffic injuries (Polinder et al., 2015).
- Patterns of injury resulting in permanent medical impairment are different for children compared to adults (Bohman et al., 2014).
- Differences in long-term outcomes for motor vehicle crash occupants vary by gender and age (Gustafsson et al., 2015).
- Trauma severity may vary for similar injuries based on age (e.g., thoracic injuries in adults have higher mortality risk than those in school-aged children) (Doud et al., 2015).

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. One reason for the lack of advanced restraints in the rear seat is the limited regulation and ratings programs targeted to these seat positions. 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.

Selected accomplishments since 2013: The importance of this priority was emphasized in a recent analysis of the applicability of the US NCAP ratings on rear seat occupant protection. Metzger et al. (2015) linked US NCAP ratings with rear seat occupant injury risk and demonstrated that better ratings in frontal crash tests were associated with improved protection for rear seat occupants (of all ages). In contrast, better ratings in side crash tests were not associated with reduced injury risk for the rear occupants. These analyses identified targets for improvement in NCAP testing to focus on rear seat restraint system performance.

The most notable advancement in this area lies in the roadmap laid out by EuroNCAP to evaluate and rate rear seat occupant protection using pediatric sized ATDs beginning in 2016. As discussed above, pediatric protection will be assessed through the use of the Q6 and Q10 ATDs in the rear rows for both frontal offset deformable barrier tests and side mobile deformable barrier tests. Metrics from several body regions will be used in the ratings. This effort will spur the development and introduction of advanced restraint designs including pretensioners and load limiters to the rear seating positions.

Care needs to be taken in considering the optimal design for the broad range of occupants in need of protection in the rear rows. Several researchers have explored the performance of these advanced restraint components with pediatric size ATDs or models. Tylko et al. (2015) evaluated the protection of the far-side seated 6 year old on booster seats through a series of lateral sled and crash tests – specifically exploring the potential benefits provided by pretensioners. Testing showed extensive head displacement, often with head contact depending on adjacent occupant; however the head displacement was decreased with the use of a pretensioner. It is important to consider fundamental biomechanical principles as these restraints are introduced and engage in collective discussion about best practices and voluntary injury criteria and thresholds that may need to be considered in addition to regulations and formal consumer testing programs which take some time to respond to technology introduction. In a preliminary study, Juste-Lorente et al.

(2014) used a MADYMO model to conduct a parametric study with the Q3, Q6 and Q10 ATD restrained in a high back booster exploring several designs and firing strategies of pretensioners. Pretensioning reduced head excursion; this was most effective if the pretensioner was applied at the buckle rather than to the shoulder belt alone. More work is needed to determine the optimal design specifications of pretensioner force and timing to protect the range of occupants – including children – in the rear seat.

LOOKING AHEAD

The second half of the workshop was dedicated to a future-oriented perspective and identifying particular challenges facing our society to continue to improve the safety of children in cars. Through this discussion, we identified 5 important questions that we thought were critical to tackle through informed and engaged dialogue from a variety of stakeholders. The questions and initial thoughts of the workshop attendees are summarized below.

1. *Advancements in models and fundamental biomechanics data – how do we best get the models and data used and accepted for tangible benefit to child occupants?*

As described above, the last decade has brought tremendous advancement in fundamental pediatric biomechanics data which through efforts by the Toyota Collaborative Research Center/Wayne State University (Shen et al., 2014), SAFER (Brolin et al., 2015, Bohman et al. 2011, Stockman et al. 2013) and the PIPER project (Beillas et al., 2013, 2014a, 2014b) among others, are being integrated into various computational HBMs. These HBMs have design characteristics that allow them to better represent key aspects of occupant restraint performance such as shoulder function and belt routing that will be important for improving restraint performance. As these efforts progress, there are important principles that must be considered:

- Common pediatric- and body-region-specific performance criteria need to be established and widely accepted. There is a need for a state-of-the art compilation of data for pediatric model validation.
- The model(s) need to document their performance against these common criteria using accepted and harmonized methods of assessing quality.
- Harmonization of models is desired; a diverse spectrum of different child HBMs is not efficient. With increasing performance of morphing and scaling tools, it may be possible to represent individual children and age groups using a limited number of validated baseline models..

An open source strategy is highly encouraged to create a sense of sharing within our community. By providing models in the public domain, they can be widely used and a broad and diverse community of users can be established. By setting expectations of sharing from beginning, we can change the business model to accelerate use of the models to actually design improved restraints and vehicles for children. The PIPER project is advocating for this approach. Open questions remain but are not unsurmountable: how is version and quality control managed and who provides management and service to the model community? We need to accept that there will problems and misuse with this approach but must be willing to take the risk.

As fundamental knowledge increases, the models need to evolve to include the capability to be modified parametrically to account for natural variations in anthropometry, structural geometry and material properties and be integrated with tools to help position the models accurately in realistic occupant positions.

2. *Child occupant protection is currently complex for families. How do we help families make the right choice – how do we make typical behavior safe? How do we simplify the usage?*

A common statistic speaks to the large percentage of child restraints that are misused and across the world there are still meaningful proportions of children who still ride unrestrained or in suboptimal restraints for their age. Tremendous investment in developed countries has been made in educating parents and caregivers as to best practice perhaps indirectly suggesting to them that correct usage of car seats is difficult and creating a perception that it is hard to do the right thing.

We as a safety community need to change the narrative and understand how to better merge typical behavior with best practice. Make the message simple and positive: highlight a few instructions and make it easy to do them reasonably well instead of conveying “this is so complicated”.

To do this, we need more than biomechanical engineers. Human factors, behavioral science and ergonomics experts need to conduct comfort studies with validated tools to rate comfort. Recent efforts to incorporate ease of use into rating systems (and therefore design specifications) is encouraging; however those ease of use metrics must be evidence-based. New child restraint designs should be more forgiving systems that understand how the environment is actually used and design from that starting point. Real occupants do not necessarily position themselves like ATD test positions. Perhaps child restraint designs that encourage people to conform to test positions should actually be viewed from the opposite perspective – quantify how real occupants behave and design child restraints to make that typical behavior safe. Lastly, while add-on restraints are likely still necessary for our youngest children, encouraging the vehicle to provide the appropriate age-specific solution at younger ages than is done currently has the potential to result in an easier-to-use approach.

3. *Our field primarily focuses on fatalities and more serious injuries. Should less severe injuries be prioritized in future crash safety policies? Can our current tools discern more mild acute injuries that may have long term consequences?*

The primary focus for child safety in cars has been on reducing fatalities and severely injured children. Severe injuries are often defined by the AIS scale, referring to injuries at an AIS3 level or more severe, leaving minor/moderate injuries at an AIS1 or AIS2 level. Many developed countries, i.e. US, Sweden; can demonstrate measurable reductions in these measures (NHTSA 2015, Carlsson et al., 2013). The Swedish parliament has taken a broader look in establishing Vision Zero in Sweden, meaning no one should be killed or seriously injured in the Swedish road transport system. Rather than simply looking at injuries that carry a high risk of fatality, their targets include injuries resulting in long-term consequences (Tingvall 1998).
It is well known that some severe injuries, for example traumatic brain injuries, may lead to long-term consequences that impact children’s daily living. However, it is also possible that several injuries at AIS1 and AIS2 levels may lead to consequences to the child over a period of time. Some may result in lifelong burden while other long-term consequences may last several months and resolve. Still, an injury with long-term consequences over several months may still have a severe effect of the child’s life. For example, a child sustaining a concussion may experience symptoms for several months in terms of headaches, fatigue and problems in concentration, affecting the child’s ability to learn and advance academically during this period (Barlow et al., 2010). The consequences to the life of the child make these “minor” injuries not so minor and their mitigation in need of prioritization.

Further research is necessary to begin to elucidate injury prevention strategies for these injuries that may be lower on the AIS scale but come with long-term consequences. Studies of injury mechanisms, injury criteria and injury thresholds are necessary. This information must be reconciled with our current ATDs and computational models to determine if those tools can be used to evaluate these injuries or further developments is needed. The advances in child HBMs described above may be the means of addressing injuries with long-term consequences.

Injuries at an AIS1 and AIS2 level, from which the child will recover from within a shorter time, are also targets for prevention. The future car fleet will include autonomous vehicles, and the question needs to be discussed, will society accept any level of injury if there is a crash, after the driver has left the control to the vehicle? There may be a connection, the less control a person has over a situation, the less likely the person is to accept an injury due to the situation. Are the expectations of prevention in autonomous vehicles higher, as you have handed over the control the vehicle and therefore you expect to emerge from a crash or near-crash with no injuries – neither minor nor severe? If the automotive industry needs to consider prevention strategies for these AIS 1 or 2 injuries, further research is needed in order to understand society's expectations of autonomous vehicles and what goals are possible to aim for. Lastly, it is important to consider how we will determine how to allocate limited research resources to either further reductions in fatal/ severe injuries vs. minor injuries with long-term functional limitations vs. minor injuries with no long-term consequences.

4. *Countries such as China and India are becoming rapidly motorized. How do we ensure adequate data collection to address specific needs? What education or innovative technology is needed to increase usage of age-appropriate restraints for each specific cultural context?*

Experience in Europe, Australia and the US demonstrates that safety improvements are accelerated with appropriate data. Lawmakers and policy experts can be compelled to action and resource investment if data can prove their constituents are at risk.

Global efforts to define common data elements and coordination of data collection, analysis and dissemination is critical. Data must be clearly accessible to key stakeholders so that its use to set policy can be facilitated. The level of detail needed from specific data collection systems 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.

Above we highlighted the activities and discussion being led by the World Health Organization and other public health entities as part of the Decade of Action in many of these settings. It is critical that the engineering community including researchers, test engineers and manufacturers partner with the public health community as success relies on such multi-disciplinary interaction. Understanding the local culture of safety and modifying restraint design and educational messages to fit that cultural context will lead to more success that assuming the Western solutions fit every locale. Novel cost-effective solutions are likely required in countries/regions like Africa, Russia, India, and Thailand.

Once data spurs the development of regulations, new products and laws, enforcement is another aspect that cannot be forgotten. Successful strategies for enforcement likely vary by region, country and sub-national area based on political structure and societal norms; however finding examples worldwide of successful enforcement initiatives and modifying their implementation for other settings is a good place to start.

5. *How do we ensure existing and emerging restraints are fully evaluated in diverse loading conditions for "real kids" in "real cars"?*

To provide comprehensive protection, a child restraint should be evaluated in a numerous different situations, including a variety of crash configurations as well as usage modes, to ensure they work in diverse real world conditions. Since this is not practically realistic, it is essential to prioritize particular test modes and design restraints based on fundamental biomechanical principles. Furthermore, since it is vital that child restraints are used every trip and that the design is forgiving for "normal use" situations, ease-of-use assessments need to be a focus.

Regulations that govern child safety represent a minimum standard and are not intended to fully encompass all aspects of protection. Consumer information testing complements regulations. It is important that the test methods as well as the ATD positioning resemble as much as possible real world safety conditions. Test fixtures need to resemble as much as possible the modern fleet. The ATDs need to demonstrate a high level of biofidelity – shaped like real children, move like real children, and measure injuries that real children experience in the field. Today, if these principles are not met, consumers may be misled by such rating program. For example, abdominal loading for children in child restraints (avoidance of which is a fundamental biomechanical principle for optimal restraint) is only to a limited extent reflected in a leading current European consumer rating program. As a result, restraints can be developed that score high on consumer tests that may not provide the best protection in the field, such as the shield system where the loads are transferred in a non-preferred biomechanical way (Edgerton et al., 2004).

The overall goal is to make sure that all children are using child restraints; any restraint is good, but ideally children should use the most appropriate restraint for their size and age and use it in a robust way every time. Ultimately, this is achieved by promoting introduction of novel, easy to use restraint designs, targeting attractiveness (from several different point of views), ease-of-use and a forgiving design which follows fundamental biomechanical principles. Research as well as innovative design initiatives are needed to reach this goal. Regulatory bodies, consumer testing organizations and vehicle and child seat manufacturers must all work towards the same objective. Together with research entities, they all have a responsibility to be guided by fundamental principles to ensure the restraints have no unintended consequences for children and if these unintended consequences exist, that there are systems in place to detect them early enough. Targeted education must be provided to guide consumer purchasing decisions that result in the protection of real kids in real cars.

CONCLUSIONS

The panel of experts convened for the Gothenburg workshop reconfirmed priorities identified at previous workshops and identified key advances in each area. 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. To address the global burden of road traffic for children and youth, the scientific community will need to engage in meaningful discussion around important questions facing our field. Having common goals and a common language will help ensure measurable change is realized.

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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.

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