Child Occupant Protection: Autonomous Driving Systems

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INTRODUCTION

Advancements in technology continue to push the automotive industry towards a world of shared mobility and varied aspects of vehicle autonomy, which potentially include non-standard seating environments and new demands for accessibility and occupant protection for all passengers. With the understanding that vehicles will still crash over the next decades, along with an increased use of ride sharing services by parents and their children; safety researchers have a heightened concern over how to keep occupants safe in these new scenarios.

As in the past few decades of crash safety research, an overwhelming amount of focus to date in crash safety of this new mobility is on the 50th percentile male. There is growing concern in the child occupant protection community that the safety of children is not a priority despite the fact today that vehicle crashes remain the leading cause of death and disability for children and adolescents (WHO, 2018). Child occupant protection research remains a critical need for industry, academia, government and safety advocacy organizations. While reductions in fatalities and serious injuries in high-income countries have been achieved, motor vehicle crashes remain a public health priority (Kahane, 2016). Over the past decades, advances have been made in protecting children when they are in position and properly restrained (Tarriere 1995, Lesire et al., 2013, Crandall et al., 2013, Yogandandan, Nahum and Melvin, 2014). However, as the most recent Global Status Report from the World Health Organization reveals, as a research community we need to continue to push to improve the safety for our children whether they are inside the vehicle or out especially as we move into the world of autonomous driving systems.

To facilitate international coordination and sharing of knowledge around this topic, the sixth biennial workshop on Child Occupant Protection: Autonomous Driving Systems was convened in September 2019, bringing together international leaders in the fields of child occupant protection, human factors, biomechanics, and auto safety. Summaries of previous workshops were presented at the 2011, 2013, 2015 and 2017 Protection of Children of Cars Conferences. The following describes the recommendations that emanated from the 2019 meeting.

PROCESS

A two-day workshop was held in which the first day focused on the following questions:

- What do autonomous driving systems mean for children and youth?
- How will the way in which children and youth interface with this new mobility potentially alter their behavior and thus their position in these vehicles?
- How do we ensure optimal protection for all age occupants as we move from a driver-centric mobility to a passenger-centric mobility?

- What types of multi-disciplinary research activities are needed to advance the safety of children, youth and young adult passengers as we move into this new era?

The second day 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 the discussion on day one, we identified 4 key contemporary sets of questions for our field and potential solutions, including new areas of research and needed collaborations, were discussed. The following sets of questions were proposed to the attendees:

1. What information or data needs to be collected for user-centered and adaptive design for seats and restraint for all? How do we encourage developers to embrace this approach?
2. Children who are not yet adult size but have transitioned out of the booster seat appear to be a vulnerable group. How do we design and optimize restraints for them until they are of adult size?
3. Describe the best path to improved tools relevant to autonomous driving systems and future mobility. What tools do we need to account for diversity of occupants, what data is needed, what is the ideal combination of computational vs physical testing?
4. What are the main points that we should speak with a unified voice concerning protecting children and families in autonomous driving systems?

This workshop included 18 individuals from diverse organizations and scientific disciplines from around the world (a complete list of attendees is contained in the Appendix):

- Behavioral scientists
- Biomechanists
- Human factors including psychology and industrial engineering
- Epidemiologists
- Government researchers
- Physicians
- Auto safety researchers
- Restraint suppliers
- Vehicle manufacturers
- Test centers and rating institutions

The initial thoughts of the workshop attendees are summarized below.

DISCUSSION

The discussions that align with the above questions are summarized in four themes.

User-Centric Seating

The primary theme that evolved from the first set of questions was that seat designers should think about both the physical attributes along with the behavior of the seated occupants. In other words, design the seat with the end user in mind in a way that protects them during a crash while allowing them to use or behave in the seat in ways that are commonly desired. As automated driving systems (ADS) become more prevalent in coming years, the design of the occupant compartment may change greatly to include seats situated at varying degrees with respect to the vehicle's primary direction of motion. These seats might also have the ability to recline to the point that the occupant is laying supine while the vehicle is in motion. This potential flexibility in seating configurations brings new challenges to protecting all occupants in the vehicle during a crash. One main focus of the workshop attendees was that this challenge is an opportunity to move away from the traditional approach to safety and seat design, which is typically focused on the optimally positioned 50th percentile male, and to focus instead on all potential occupants in more user-centric positions, especially children.

The first question that arises is, how do we get industry and regulatory agencies to understand the need and benefits associated with user-centric seats? It is important that we educate and empower the end user with the knowledge of how "personalized restraints" could benefit them in a crash scenario. If we increase the road safety literacy of the end user, or in this case the individual purchasing the vehicle, they could demand that personalized restraints and user-centric designed seats be included in the base packages of automobiles to increase occupant safety. Thoughts on how to educate the end users included the use of social media, along with publishing guidelines on potential best practice for personalized restraints for both the technical field and for on-line bloggers and "influencers."

In order to define new guidelines and test procedures on user-centric seating and personalized restraints, more data are needed world-wide. Up-to-date anthropometric data, along with kinematic and kinetic data associated with the body's response to numerous loading directions while positioned from seated to supine are critical in understanding how to keep an occupant safe during all crashes. These data could be generated using a combination of finite element model simulations to determine worst case crash scenarios, and anthropomorphic test devices (ATD) or crash-test dummies to better understand those critical outlying cases. Fundamental research is also needed using post-mortem human subjects (PMHS) to ensure the tools being used to conduct these assessments are valid. In addition, and just as critical, we need to better understand human behavior during transport to deepen our knowledge on how people use (and want to use) restraints, what are individual's expectation of the seats and safety systems, what is appropriate and inappropriate behavior that might occur while using the seat, and finally understand how the seat design could assist the occupant in behaving in a manner that ensures the safety systems are optimized during the crash. To better understand occupant behavior during transport, Naturalistic driving studies can be used to better understand the end user's interaction with seats and restraints and usability studies with novel designs are needed to elicit new ideas. All of this research could lead to a formalized evaluation process that defines the guidelines most critical to ensure any and every occupant's safety in a user-centric designed seat with personalized safety restraints.

We have to be aware and prepared, that with new modes of transportation, behavioral changes such as travelling unrestrained may increase. How can we prevent new unsafe behaviors in new settings? How can we nudge the user from thinking "can we travel unrestrained now?" to a more natural and continuous way of staying restrained. Let's use the user-centric design as a mean of addressing. Also, we should not forget the fundamental basics of safety, and don't get blinded by "cool" futuristic technology. At the same time, we should leverage the opportunity that new technology can support our purpose, for example smart monitoring systems that can help adapt the restraint systems and seat support.

Finally, the topic of rideshare (Lyft, Uber, etc) safety was discussed as it relates to the idea of user-centric seating and safety. The majority of the discussion focused on identifying currently available portable restraints, specifically for children, that could be used to protect the child occupants as the popularity of rideshares continues to increase around the globe. It was determined that more data on child use of rideshares are needed: typical usage, crash rates, crash types etc to better understand this issue and potential safety guidelines that could be created to better educate the users of these services.

Keeping Graduates of Boosters Safe

The second topic of interest from the workshop focused on maintaining the safety of children who have graduated from boosters, but appear to be vulnerable as they are not physically large enough to properly interact with current restraints. It was noted by many of the attendees that more research and focus is needed in general on the safety of rear-seat occupants, which echoes the findings of a study conducted by the Insurance Institute of Highway Safety and Children's Hospital of Philadelphia (Fein et al. 2019, Jermakian et al 2019). The rear-seat is a likely location of children that have recently graduated from boosters, so any improvement in rear-seat safety for adult occupants would also likely improve the safety of these vulnerable occupants.

One solution discussed at length was to develop a tool for the end user to evaluate good belt fit on their child. One example of a useful tool might be as simple as adding shoulder height labels on the vehicle seat back or booster seat back indicating appropriate restraint fit as demonstrated by Brown et al (2010). The findings indicated that participants made significantly fewer errors in judging restraint appropriateness for test mannequins when the restraints included shoulder height labels. While shoulder height labels might improve proper shoulder belt placement across the child's clavicle, it is critical we continue to learn more about the belt performance during a crash. It was suggested that a future study could be conducted to better understand the most critical aspect of belt fit or performance for these vulnerable occupants during a dynamic crash event. Once researchers can clearly identify the key aspect of safety for these occupants, a tool could be created to ensure safety for graduates of boosters. Finally, it was also noted that the created tool for proper belt fit should not be child specific as it may also assist smaller adults.

In addition to creating a safety tool or guidelines to assess proper belt fit on rear seat occupants, discussion focused on changes that could be made to the geometry of the current occupant space in the back of the vehicle. One critical point that kept arising concerned the length of seat pans and the booster seats. It was noted that if the length of seat pans were shorter to begin with, but could be lengthened depending on the height of the occupant, it would greatly reduce variation in occupant posture and help improve the shoulder belt location. Many of today's high-end vehicles include motorized front seat pans that can be lengthened, so perhaps the technology exists to allow rear seats to also adapt to the size of the occupant.

Finally, discussion focused on education and outreach to discuss with families the importance of proper belt fit at each transition stage as children grow and become young adults. It is important to stress to children and their parents that graduation from a booster seat is not a milestone to celebrate in life. Instead, they should focus on delaying graduation until the belt fit using the regular restraint systems is at the very least the same as it was with the booster. If the end users were educated better on why proper belt fit is critical to keeping their children safe, they would be less likely to celebrate booster graduations and push to maintain the use of the booster longer. Also, a built in adaptivity, can be an attractive design solution, and the point of transferring from "child seat" to "adult" seat could be made more gradually. Instead of a "graduation", the transition would be made through a slow "personalized" process of adaptivity.

Safety Tools

The third topic of the workshop focused on improving the current tools we use to predict occupant safety, mainly ATDs and finite element human body models (eg. THUMS, GHBMC, PIPER) for use in future automated vehicles. This topic ties back into the first discussion point by looking to ensure safety for all occupants, not just 50th percentile males. It was quickly agreed upon that the base data and research used to create current ATDs and also to validate the current set of human body models needs to be assembled in order to help educate young researchers. Many attendees of the workshop had concerns that these tools are currently being used incorrectly, thus the need for a publicly available review of all current safety tools. It would be very beneficial to assemble a webinar series which would review the current status of all safety tools so researchers better understand the tools, including their limitations to ensure they are being used properly. All tools, whether physical or simulated, have limitations that restrict when they should be used to predict occupant safety.

It was largely agreed upon that finite element human body modeling is the future of crash test safety and that perhaps in the coming years regulatory agencies will adopt simulations as safety standards without the need to complete expensive, physical tests with ATDs. In order to advance the use of models and simulations to predict occupant safety, it is critical that global standards are defined in regards to model validation and certification. One reason the use of simulations is appealing is their ability to quickly look at omni-directional loading scenarios vs the physical ATDs which are typically only biofidelic in one direction (i.e. frontal or side) and thus can only be used in a single crash direction. Current research is also focused on morphing the models to various sizes and ages and thus allows them to predict the safety for a larger range of occupants. This type of simulation is helping to change the paradigm of model validation to subject specific model validation, which is critical in ensuring the models are performing accurately in predicting occupant safety. While the majority of morphing HBMs has focused on adult models, the open source validated PIPER child models can be scaled between a 1.5y child to a 6y child. There have been a few published models which represent a 10y child, but those models are not frequently used, nor have they been morphed to represent older children and teenagers.

There are a number of areas in which we need to continue to improve the finite element human models. Currently the models are not accurate at predicting injuries to occupants at lower severity crashes, which may occur more frequently with highly automated vehicles. In order to improve their accuracy, models with active musculature are necessary, for example neck and back muscle activation during rear-impact crash scenarios are critical in predicting kinematics and injury outcomes. Current finite element models are very detailed, contain thousands of elements and may take up to 24-36 hours of run time on a large bank of servers. One discussion point examined the idea of having simplified models that would quickly look at overall occupant kinematics during numerous crash scenarios and identify a "worst-case" scenario based on potential injury to the occupant. This would be followed by using a very detailed model that would run the defined "worst-case" scenario to identify the potential injuries to the occupant. This "worst case" scenario could also be physically tested with PMHS to help validate the injuries predicted by the detailed finite element model. Using this combination of simplified models, tools, and highly detailed models, would allow for researchers to more quickly and accurately look at the safety of all occupants regardless of age, sex and size in numerous crash scenarios. Finally, open access to these models in order to ensure the best safety tools are being used across the globe was discussed as vital to the process.

In order to continue to improve the biofidelity of both finite element models and the ATDs the attendees discussed a number of research areas in which more data is needed. Specifically, when looking at the protection of children, we are still lacking critical data on tissue properties and injury tolerances that would allow HBMS to accurately predict injuries during a crash. It is also important to conduct more low severity research (eg. vehicle maneuver situations) with children to look at muscle recruitment and activation patterns as compared to adults. There are ongoing research programs (NHTSA, ENOP) to produce validation data for adult HBM and ATD to address upcoming challenges with new seating configurations. Also, efforts are ongoing to improve the adult ATDs, with focus on Thor 50th, in order to address challenges in reclined sitting positions (AVOS, NHTSA). There are no similar efforts ongoing for the pediatric population. Just as efforts are made to improve the current adult tools, similar efforts should be made for the pediatric tools, in order to keep pace with the development of AD vehicles and continue to improve the tools to improve their capability of predicting injuries.

Voice of Safety

Finally, the attendees focused on defining a unified voice, or message, that those stakeholders in child safety could communicate throughout the world concerning the protection of children in future autonomous driving systems. As a group it was determined that this voice should be shared with industry, academia and regulatory agencies through publication of papers, lectures and speaking opportunities at research conferences. The following were the critical points as decided upon by the attendees of the workshop –

- Cars will still crash
    - As we move into the world of increased vehicle automation, there will eventually be a mixed fleet of human drivers and automated vehicles sharing the same roads for several decades to come. Due to this interaction, there will be crashes and occupants will still need safety restraints to protect them. One important note is that an increasing amount of crashes will be preceded by maneuvers targeting avoidance of the crash. When not avoided the severity of the impact will change, which could lead to lower severity crashes or different crash modes. In these crashes, representing active musculature in the safety tools is critical in predicting occupant safety.

- Child adapted systems needed for EVERY trip
    - Shared mobility (e.g. taxis, rideshares) is not an exception for safe travels for children. Restraint usage rates in these modes are notably less than in private vehicles. It is critical we begin to design seats and safety restraints focused on the user, no matter the age, sex or size of the occupant, but also acknowledge that the type of trip puts specific demands on the design. The vehicle seat and accompanying restraint system should allow for all occupants to be safe in all crash scenarios moving forward regardless of position in the vehicle. The design of the seat should also promote behavior of the occupant that allows the individual to be comfortable and safe.

- Children are included in “diversity”
    - Unfortunately, when the word “diversity” is being used in our field, it typically refers to differences in sex or perhaps size, but rarely does it include discussion of children. We need to raise awareness of the safety community of this discrimination and make it

obvious that children are included in the term "diversity" as well. Children are not small adults, they need special consideration. We need to continue to focus on the protection of children as the field moves in the direction of shared mobility and varied aspects of vehicle autonomy. Children have to be included in the discussion, NOW, it cannot wait until solutions have been developed for adults.

- Make safety a priority; including outside of the vehicle
  - As mentioned earlier, cars will still crash for decades to come and this includes bicycle, scooter, and pedestrian crashes. Collision avoidance and protective systems are still critical in protecting all road users and safety needs to remain a priority in industry, academia and regulatory agencies.

CONCLUSIONS

The panel of experts convened for the Gothenburg workshop focused their attention on a world of shared mobility and varied aspects of vehicle autonomy, which potentially include non-standard seating environments and new demands for accessibility and occupant protection for all passengers – including children. As stated in past workshops, vehicle restraint design should be user-centered, inclusive and universal and encompass variations in both the traits of the occupant (e.g. size, BMI, age) as well as the states of those occupants (e.g. postures, distraction, shifting priorities). In order to assist with restraint design, current safety tools such as ATDs and HBMs need to continue to evolve and be used together to allow for researchers to more quickly and accurately look at the safety of all occupants. Recent emphasis on improving these tools for this future mobility state have focused on adult occupants; a similar focus needs to be placed on the evolution of child-specific tools. Otherwise, child safety will lag behind. Finally, critical safety points were defined as a unified voice for all stakeholders in child safety to use in future publications and conference presentations to ensure that the safety of all road users is in focus as we move into a world of autonomous driving systems.

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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
- Mikael Ljung Aust, PhD - Volvo Cars
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