Child Kinematics in the Rear Seat during Driving Manoeuvres

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Introduction

Summarizing crash data (NASS-CDS 1991-2005) on rear seated children aged 4-12 years, second to rollover, the highest MAIS3+ injury risk was seen for side impacts situations (Bidez, 2006). However, there were more children injured in frontal impacts, due to the high frequency of frontal impacts compared to other crash direction. Furthermore, several of the injured children were restrained, indicating that current restraint systems have potential for further improvements.

Regardless of crash direction, the head is the most common severely injured body region among children in motor vehicle crashes (Jakobsson et al. 2005, Howard et al. 2004, Durbin et al. 2003). In a review by Bohman et al. (2011a) containing 27 cases of rear-seated children, restrained by seat belts in frontal crashes, who sustained AIS2+ head injuries, three distinct injury causation scenarios were identified. These include head contact with seatback, head contact with side interior, and no evidence of head/face contact. For the seatback contact scenario, the vehicle's movements (due to oblique impacts and/or manoeuvres) were likely to contribute to occupant kinematics inboard the vehicle, causing a less optimal restraint of the torso and/or torso roll-out of the shoulder belt. For the side interior contact scenario, the oblique impact and/or manoeuvres forced the occupant towards the side interior. Thus, from the perspective of optimally protecting the child it is essential to further understand the child kinematics and consequences in situations where the driver makes an extensive vehicle braking or swerving manoeuvre before the crash.

The current study presents the methodology and first results from a driving study investigating the effect of braking and swerving manoeuvres on the child's kinematics and the seat belt position. Specifically, the aim of the study is to quantify the kinematics of child occupants during swerving and braking manoeuvres with a focus on the child's inboard lateral or forward movement and seat belt position relative to the child's shoulder. In addition, the feasibility of child test dummies to reflect the child occupant kinematis is to be evaluated.

Methods

A manoeuvre driving study was conducted on a closed-circuit test track involving braking and swerving manoeuvres with 16 children aged 4-12 years restrained in the right rear seat of a modern passenger vehicle (Volvo XC70 model year 2010). A professional test driver drove the test vehicle and a parent was seated in the front passenger seat. While traveling at a velocity of 50 km/h, the vehicle was quickly turned 90º to the right to represent the swerving manoeuvre. The braking manoeuvre was conducted by braking the vehicle as fast as possible from 70 km/h to a full stop. A sketch of the swerving manoeuvre and the vehicle lateral acceleration is shown in Figures 1a and 1b, respectively. The longitudinal acceleration during the brake sequence is shown in Figure 1c.

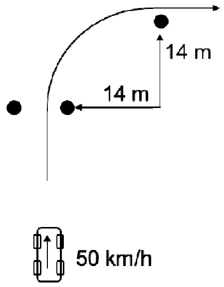

Figure 1a. Sketch of the swerving manoeuvre

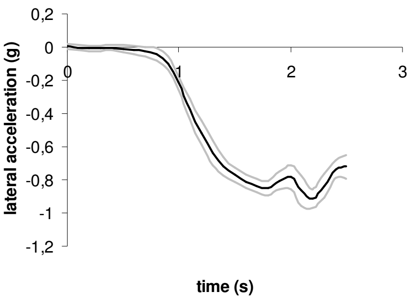

Figure 1b. Vehicle lateral acceleration during swerving manoeuvre

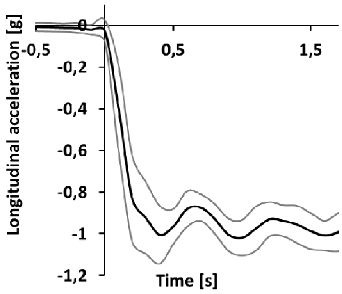

Figure 1c. Vehicle longitudinal acceleration during braking

The children were exposed to two swerving and one braking manoeuver in each of two different restraint systems. They were unaware of when the swerving and braking would take place. Each child used two different restraint systems, according to their stature. Eight children of 105-125 cm stature used boosters, with and without backrest (Figures 2a and 2b). The eight taller children (135-150 cm) used booster without backrest (Figure 2a) and seat belt only. Also, child crash test dummies of different sizes were run in the same set-up.

Four film cameras were fixed in the vehicle providing a front view of the child, a perpendicular lateral view and two different oblique views (Figure 2c). Vehicle data including velocity, acceleration in forward and lateral direction, brake pressure and steering wheel angle was recorded together with shoulder belt force. Film analysis was used to quantify the child kinematics and lateral position of the child relative to the position of the shoulder belt throughout the event. The test set up and the analysis of the swerving manoeuvre are further described in Bohman et al. 2011b.

Figure 2a. Booster without backrest

Figure 2b. Booster with backrest

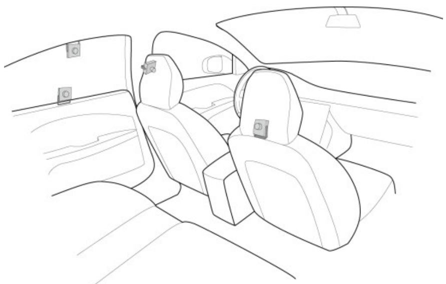

Figure 2c. Sketch of film camera placements

Results

In total 64 swerving and 32 braking events were completed. The 16 children experienced two swerving and one braking events in each of the two restraint conditions. The upper body kinematics and belt position on the shoulder was studied.

Snapshots of sitting postures before and during the swerving manoeuvre are shown as an example in Figure 3. The children moved laterally about 100mm, regardless of stature or restraint system. However initial seat belt position and other factors resulted in differences in the shoulder belt slipping off the shoulder. Among shorter children, the belt slipped off in almost 2/3 of the turns when seated on a booster without backrest while the belt remained on the shoulder when seated on the booster with backrest. For the taller children no belt slip off occurred. The distance the shoulder belt moved relative to the shoulder was the same regardless of restraint system. However, the initial position of the shoulder belt was closer to the neck when the children were restrained by seat belt only. Taller children seated on BC demonstrated a shoulder belt position far out on the shoulder during the swerving event. Details can be found in Bohman et al. 2011b.

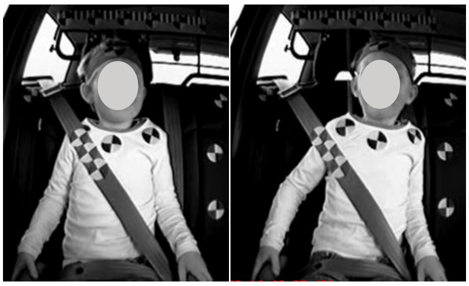

Figure 3. Sitting posture before and during the swerving manoeuvre

In general, the forward motion during the braking manoeuvre is in the same range for the taller and shorter children, Figure 4. Comparing the shorter and taller children during the braking events, differences can be seen in the head rotation and curvature of the neck and spine. Comparing the different restraint systems, the forward kinematics are not substantially affected, however the maximum excursion is depending on the initial sitting posture and shoulder belt position on shoulder. As an example, the shorter children when using booster with backrest their initial sitting posture is further forward as compared to when using booster without backrest, thus resulting in a more forward position during maximum excursion. Analysis of the child kinematics and crash test dummies during the braking event is ongoing and will be published.

Figure 4. Forward excursion during braking for a shorter child to the left and a taller child to the right when seated on booster.

The analysis from the swerving manoeuvre tests with the crash test dummies are still to be published. The preliminary analysis reveals that the child crash test dummies, when used in this non-crash situation, lack correspondence in the global kinematics of the children. Also, the correspondence is different for the various dummies in an inconsistent way between the two different manoeuvres. Thus, with the ambitions to develop an objective method for pre-crash manoeuvres it is essential to analyse in detail the feasibility of the different crash test dummies of today and potential improvements to be done.

Discussions

For an optimal protection of the child during a crash, the child's position in relation to the seat belt is an essential part and poses a special challenge. On road driving studies have shown that the sitting postures of children in the rear seat vary and depend on the specific restraint system. Research by Charlton et al. (2010) provided understanding of how a total of 25 children up to age 8 sit in vehicles while riding in the rear seat. A study by Andersson et al. (2010) involving six children between three and six years of age evaluated differences in sitting postures for two different types of belt-positioning boosters with backrests in the rear seat. Jakobsson et al. (2011b) presented data on six children aged 8-12 on sitting postures and shoulder belt position comparing booster without backrest and seat belt only. These studies contribute with knowledge of children's preferred sitting postures and behaviour when riding in the rear seat of a passenger car. The present study adds on knowledge on the kinematics of a child relative to the seat belt in a real world manoeuvre situation. This is an important part since real world crash data analysis have indicated pre-crash vehicle manoeuvres are frequent and potentially contribute to the injury outcome.

This study of a total of 64 swerving and 32 braking manoeuvres with 16 children experiencing two swerving and one braking events in each of the two restraint conditions, provides valuable and unique knowledge on possible pre-impact positions of children. A summary of some of the results are presented in this study, while some parts are still to be published. The kinematics and shoulder belt position for the 16 children during the swerving manoeuvre was presented and discussed in Bohman et al. (2011b). Further publications will follow on child passenger kinematics during the braking sequence as well as an evaluation of the child crash test dummy kinematics during pre-crash manoeuvres.

The method developed to study children's kinematics during pre-crash vehicle manoeuvres included test procedure, data collection and analysis. Repeatable test performance was achieved by placing cones on the test track to indicate where the braking and the turns should start and end, and by using the same vehicle and professional driver throughout the entire study. The extent of braking and turning was chosen to simulate "emergency" manoeuvres trying to avoid a crash. Details regarding repeatability and relevance for real world pre-crash swerving situations can be found in Bohman et al. (2011b).

An important part of the test procedure was the instructions to the children. Although it was believed that a relaxed child would better simulate a real life situation, i.e. when a child is not prepared for a quick an unexpected manoeuvre, it was determined that no specific instructions should be given, since the youngest children may have difficulties understanding the instructions. This resulted in some children supporting themselves with their hands and some not. It was more common among the shorter children to support themselves, but some of them still slipped out of the shoulder belt during the swerving manouevres. A significant effort was put into developing methods of categorization of belt position during the swerving manoeuvres and categorizing the sitting postures during braking and swerving manoeuvres. More details are provided regarding the methodology in Bohman et al. (2011b).

Differences between the shorter and taller group of children could be seen, both in respect to differences in global kinematics and torso/spine bending motion. For the taller children no belt slip off occurred during the swerving manouevres, while for the shorter children the belt slipped off in almost 2/3 of the turns when restrained by booster without backrest. For the shorter children when restrained in booster with backrest, the backrest showed potential to maintaining the shoulder belt on the shoulder, but it is not known whether the backrest of the booster will continue to keep the shoulder belt in position during a frontal impact when seat and the child are in such a pre-crash position. For the taller children, the initial position of the shoulder belt was crucial for the position of the shoulder belt at maximum lateral position in the swerving manouevres. In the braking event, the maximum excursion was dependant of the initial sitting position, thus a more forward excursion could be seen when the child was restrained using the booster with a backrest. This may have implications on the relative head impact exposure in case of a subsequent crash. The differences in kinematics between the group of taller and shorter children emphasize need to further investigate the shoulder belt restraint effect on chidren of different sizes.

This study provides details in child kinematics during swerving manoeuvre and braking situations, offerering valuable input both to safety system development, dummy design and test methods development. The results illustrate the importance of understanding the kinematics of a child relative to the seat belt and position in the vehicle in a real world manoeuvre situation. Real world safety of rear seat occupants, especially children, involves evaluation of protection beyond standard crash testing scenarios. The results from this study contribute significantly to explore the complete context of rear seat protection, highlighting the importance of pre-crash posture and behaviour.

The present study is a part of a research project at SAFER, Vehicle and Traffic Safety Centre at Chalmers, where researchers at Chalmers, Saab Automobile, Autoliv and Volvo Cars cooperate with the aim to further improve safety for forward facing children (from 4y) to small adults in the rear seat. The research project if further presented in Jakobsson et al. (2011a).

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References

Andersson M, Bohman K, Osvalder A-L. **Effect of Booster Seat Design on Children's Choice of Seating Positions during Naturalistic Riding.** The 54th AAAM Annual Conference, Annals of Advances in Automotive Medicine, 2010

Bidez M. **A Critical Safety Need for Children Ages 4-12 Years**. Docket No. NHTSA-2006-26555, 2006

Bohman K, Arbogast K, Boström O. **Head Injury Causation Scenarios for Belted, Rear-Seated Children in Frontal Impact**. Traffic Injury Prevention, 12:62-70, 2011a

Bohman K, Stockman I, Jakobsson L, Osvalder A-L, Boström O, Arbogast KB. **Kinematics and Shoulder Belt Position of Child Rear Seat Passengers during Vehicle Manoeuvres.** The 55th AAAM Annual Conference, Annals of Advances in Automotive Medicine, 2011b

Charlton J, Koppel S, Kopinathan C, Taranto D. **How do Children really behave in Restraint Systems while Travelling in Cars?** The 54th AAAM Annual Conference, Annals of Advances in Automotive Medicine, 2010

Durbin DR, Elliot MR, Winston FK. **Belt-positioning Booster Seats and Reduction in Risk of Injury among Children in Vehicle Crashes**. JAMA (Journal of the American Medical Association), 2003; 289(21): p2835-40

Howard A, Rothman L, McKeag A, Pazminoi-Canizares J, Monk B, Comeau JL**. Children in Side-impact Motor Vehicle Crashes – Seating Positions and Injury mechanisms.** J Trauma 56:1276-1285, 2004.

Jakobsson, L, Isaksson-Hellman I, Lundell B. **Safety for the Growing Child – Experiences from Swedish Accident Data,** Proc of 19^{th} Int. ESV Conf., Paper no. 05-0330, Washington DC, USA, 2005

Jakobsson L, Bohman K, Andersson M, Stockman I, Boström O, Svensson M, Svanberg H, Wimmerstedt M, Arbogast KB. **Rear Seat Safety in Frontal to Side Impacts – Focusing on Occupants from 3yrs to Small Adults**. ESV paper no. 11-0257, Washington DC, 2011a

Jakobsson L, Bohman K, Stockman I, Andersson M, Osvalder A-L. **Older Children's Sitting Postures when Riding in the Rear Seat**. Ircobi Conference, Krakow Poland, 2011b

Stockman et al. **Kinematics of Child Volunteers and Child Anthropomorphic Test Devices during Pre-crash Braking in Real Car Environment**. To be published

Stockman et al. **Kinematics Comparison of the ATDs during Vehicle Maneuvers**. To be published