A Preliminary Study on Responses of 6YO Child Occupants in Front Impacts with and without CRS

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Abstract: The child restraint system （CRS）are used for child occupant protection from passenger car impacts, but it was found that older children often didn't use CRS in cars. They used adult seat safety belts or sat in the car without any restraint systems. This is one of the important reasons that child occupants are injured in passenger car impacts. This study aimed to analyze the dynamic responses of child occupants in frontal impacts in terms of accelerations of head, chest and neck loads. For this purpose, a 6 years old Hybrid-III dummy model was used to simulate child occupant in three different restraint conditions in front impacts. The simulations were implemented by using MADYMO program. The results showed that using booster cushions and booster seats has almost equal effectiveness on reducing head accelerations, chest accelerations and neck loads of the dummy model in front impacts. It is confirmed that using CRS properly can minimize the injury risks of child occupants in frontal impacts.

Key words: older child occupant, CRS, dynamic responses，injury

1 Introduction

The child occupant safety in car and child restraint system (CRS) have been studied using accident data. DeSanti Klinich et al.(1993)[1] carried out a study using data from the National Accident Sampling System(NASS) database and found that although older children represent 43.1% of child occupants involved in accidents, they receive 55.4% of the reported injuries suffered by children. A lower restraint usage rate (56.2% compared to 63.4% for younger children) partly accounts for this disproportionate amount of injury. However, when restrained, fewer older children remain uninjured compared to younger children (62.8% vs. 70.8%). The number of older children receiving injures decreases with restraint use (63.6% injured for unrestrained vs. 37.5% injured for restrained). It indicates that older children (aged 6—12 years) may deserve more attention from automotive safety researchers.

Th.Hummel et al. (1997) [2] based on a material of the German Motor Insurance (593 restrained children 0 to 12 years involved in 448 car accidents) and found that children up to the age of five years were usually placed in child protection systems and that only a few were restrained using an adult seat belt and only 8% traveled without any kind of protection. In the case of children between the ages of six and eleven years, only 27% used a special child protection system, 50% used an adult seat belt and almost one out of every four children in this age group did not use any kind of safety protection. There was a trend to a greater severity of injury in children who were restrained with an adult seat belt only. And the number of children sustaining MAIS2+ with adult seat belt only was almost three times more than children with booster cushions and three-point adult seat belts.

Khaewpong et al (1995) [3] found that children occupants used adult seat lap/shoulder belts too early, the head and neck were easy to injure. When using booster cushions, the injuries might be mitigated. It was recommended that 6－12 years children remained using booster cushions or booster seats.

Children's stature aren't scaled by adults' simply. This is one of important factors during designing child protective systems. The child restraint systems (CRSs) are designed by the characteristics of children and aimed to provide full protection to children. At present, CRSs in market are mainly divided into three kinds: infants use (0-1 years), younger children use (1-5 years) and older children use (5-12 years), etc. The types of infants use are not common in market. The younger children use are common and include forward-facing, rearward-facing and syllepses. The older children use are boosters. When the older children are boosted, they can use adult seat belts properly.

Comparing older children with younger, it can find that the mass of the older child head is proportionally less and the neck is stronger. However, there are still major differences as compared to adults. The iliac spines of the pelvis, which are important for good lap belt positioning and for reducing risk of belt load into the abdomen, are not well developed until about 10 years of age. The development of iliac spines, together with the fact that the upper part of the pelvis of the sitting child is lower than of an adult, are realities that must be taken into consideration in the design, in order to give a child the same amount of protection as an adult. The booster raises the child, so that the lap part of the adult seat belt can be positioned over the thighs, which reduces the risk of the abdomen interacting with the belt. The booster also gives the child a more upright position, so he/she will not scoot forward in the seat to sit comfortably with their legs. This is a more safe position since slouching may result in very bad belt geometry. Other advantages of boosters are after the child is boosted, will have the shoulder part of the seat-belt more comfortably positioned over the shoulder and will also have a better view. [4]

Kate de Jager et al. (2005) [5] examined the following databases: CREST, CCIS, GIDAS, GDV, IRTAD and LAB. They found that to the restraint type of booster seat and adult seatbelt, head is still the most important body area in terms of frequency of injury, but the relative importance of abdominal injuries increases with such restraint systems. Based on the review of child occupant injuries related to CRS systems used in front impact, injury measures were recommended for the head, neck, chest, abdomen/lumbar spine and pelvis.

The investigations from the National Highway Traffic Safety Administration (NHTSA) showed that the risk of injury among child occupants in front seating position is higher than in rear seating position in traffic accidents. NHTSA proposed that up to 12 years old child occupants should sit in rear seating position[6]. Consequently, this paper analysed mainly the dynamic responses of child occupants in rear seating position in frontal impacts in terms of head accelerations, chest accelerations and neck loads. The results confirmed that properly using CRS can minimize the injury risks of child occupants in frontal impacts.

2 Methods

This paper introduced the computer simulation method of multi-body model. The simulations were implemented by using MADYMO6.2.1 program [MADYMO, Delft, the Netherlands]. Three mathematical models (Table 1) were developed: (1). only three-point adult seat belt, (2). booster cushion and three-point adult seat belt, (3). booster seat and three-point adult seat belt (Figures 2 through 4) . And simulated the dynamic responses of a child occupant in full front impact with 56km/h vehicle velocity. The models comprised Hybrid-III 6 years old dummy model, booster cushion/booster seat and vehicle rear seat model including safety belt system.

Table 1. Simulation configurations

Number	Configuration
Simulation 1	Only three-point adult seat belt
Simulation 2	Booster cushion and three-point adult seat belt
Simulation 3	Booster seat and three-point adult seat belt

2.1 Dummy model

The three models all chose Hybrid-III 6 years old dummy model from MADYMO6.2.1 database. (see Figure 1)

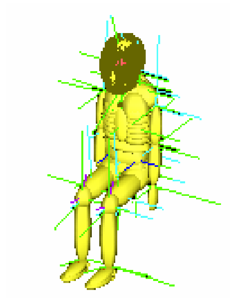


Figure 1: MADYMO model of a Hybrid-Ⅲ 6 years old dummy

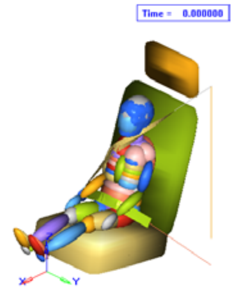


Figure 2: Only three-point adult seat belt

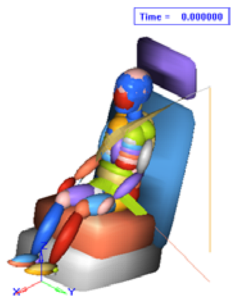


Figure 3: Booster cushion + three-point adult seat belt

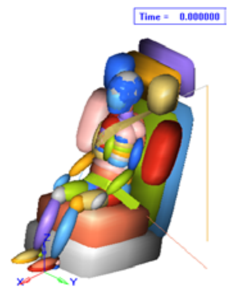


Figure 4: Booster seat + three-point adult seat belt

2.2 Booster seat/cushion model

The first model didn't use any booster seats/cushions. The second model used a belt-positioning booster cushion that based on MARIO (II+IIIgroup) booster cushion in market. An ellipsoid describes the geometry of booster cushion. The third model used a belt-positioning booster seat that based on KID (I+II+IIIgroup) booster seat in market. The geometry of booster seat is described by 7 ellipsoids.

2.3 Vehicle seat model

The three models used the same vehicle seat model, that is, left outboard position of rear seat in common sedan. The geometry of vehicle seat model is described by three ellipsoids that represented seat base, seat back and headrest respectively. The same three-point adult seat belt system was modeled in three models. The three-point belt system is of a hybrid, the main seat belt is made up of FE shell elements, while the ends are modeled by non-linear elastic springs. The FE belt provides a contact with the dummy and the booster seat/cushion, while the multi-body springs allow for advanced seat belt parameters, like slack and pretension, etc. The belt system also included retractor, webbing grabber and pretensioner.

2.4 Model preparation for simulation

There are two critical steps during the development of models. Firstly, initial positioning of the dummy was performed by applying a gravitational force on dummy (when using boosters, a gravitational force should be also applied on the boosters). By pre-simulation, dummy penetrated the seat base and seat back. When the equilibrium was obtained, initial positioning of dummy was completed. Secondly, initial positioning of safety belt on dummy was performed by applying a small rearward tension in the end points of belt without any forces or fields. The FE parts of belt were wrapped around dummy. When the equilibrium was obtained, initial positioning of safety belt on dummy was completed.

2.5 Child injury criteria[7]

Head Injury Criterion: NHTSA is adopting HIC36 with a limit of 1000 for all tests with the Hybrid III and CRABI dummies.

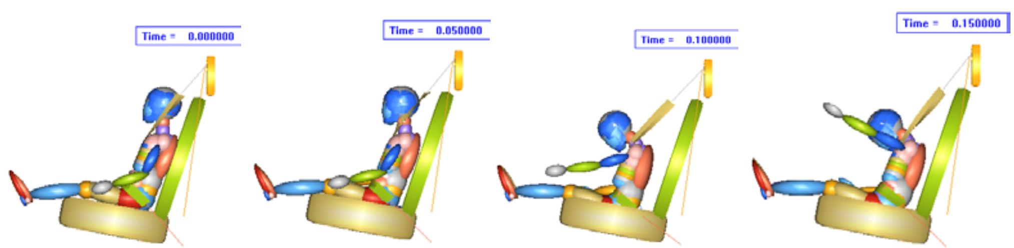
Chest injury criterion: chest injury risk is evaluated on the basis of sternum deflection, sternum deflection rate, viscous criterion, and thoracic spine acceleration. A sternum deflection of 60mm represents either a 45% or 70% risk of an AIS3+ chest injury depending on whether the airbag or seat belt causes the chest deformation. A safety need for adopting the proposal has not been established by NHTSA.

Nij: The Nij is a linear combination of neck axial force (F_Z) and the bending moment about a lateral axis passing through the dummy's occipital condyle (M_Y). But Nij is not yet incorporated into FMVSS.

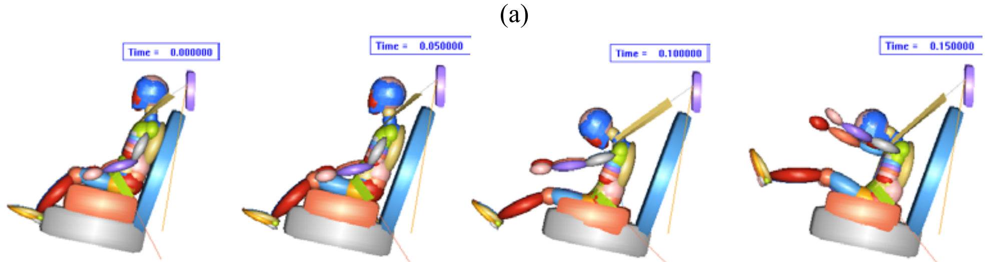
2.6 Parameters study

The three models all modeled restrained child dummy in this paper. The parameters of the dummy restrained parts were study objectives. At the same time, referring to the cases involving boosters from literatures, chose head accelerations, chest (T1) accelerations and neck loads as study parameters. Moreover, these parameters are also used for injury criteria calculations.

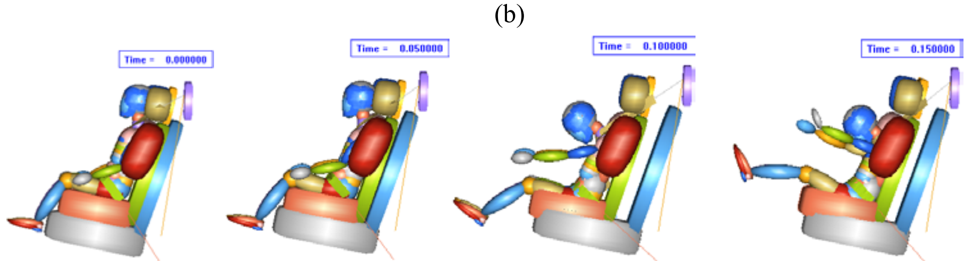
3. Results



(a)



(b)



(c)

Figure 5: the kinematics of the simulation (a) only three-point adult seat belt, (b) booster cushion and three-point adult seat belt, (c) booster seat and three-point adult seat belt

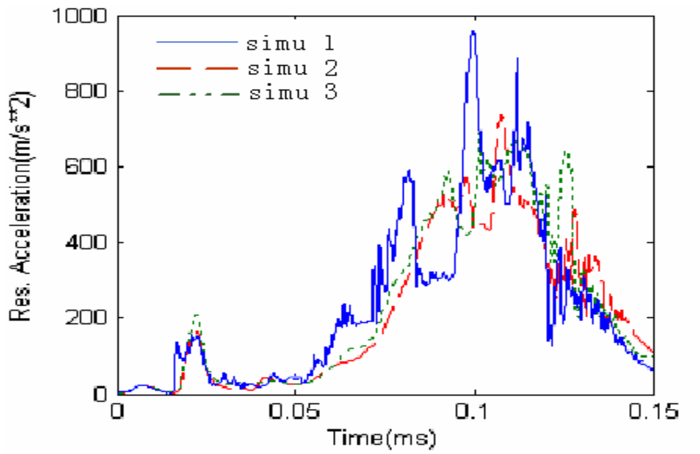


Figure 6: head resultant acceleration

In Figure 6 the resultant accelerations of three models are shown. Figure 6 shows the head resultant acceleration of dummy dropped distinctly when used booster cushion and booster seat. Comparing with the head resultant acceleration peak (95.522gm/s^2) with only three-point adult seat belt, the head resultant acceleration peak decreased 23.2% when used booster cushion, decreased 27.8% when used booster seat. To the three models, the maximum absolute values of resultant acceleration appeared at the moment that neck resultant loads got to the maximum values.

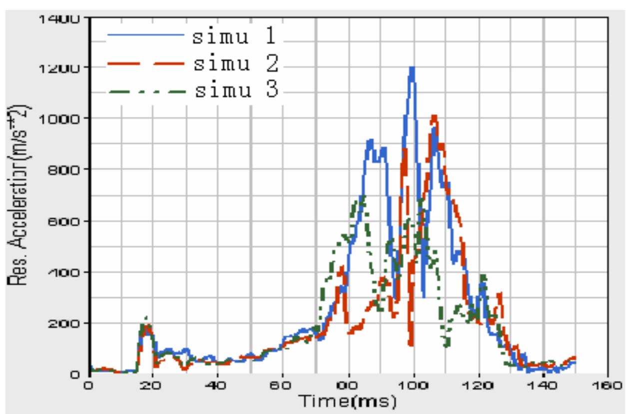


Figure 7: chest resultant acceleration

Figure 7 gives the chest resultant accelerations of three models. Comparing with only three-point adult seat belt model, shoulder part of safety belt crossed dummy thorax properly when dummy was boosted and the thorax arbitrary motion was reduced. Consequently, the chest resultant acceleration peak decreased from 120.23gm/s^2 to 120.23gm/s^2(with booster cushion) and 69.75 gm/s^2(with booster seat).

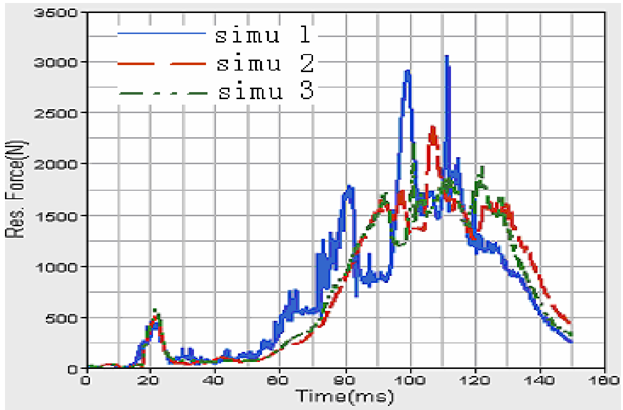


Figure 8: neck resultant force

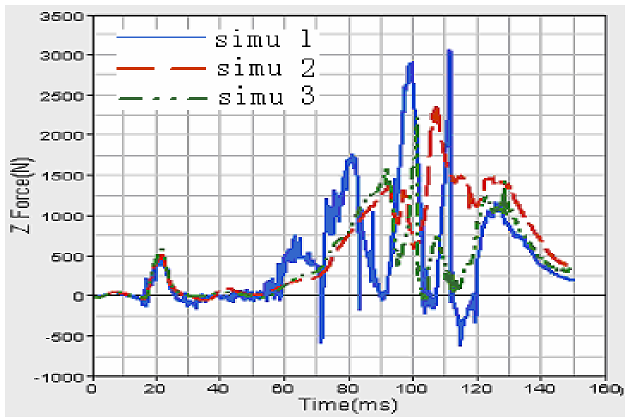


Figure 9: neck Z-direction force

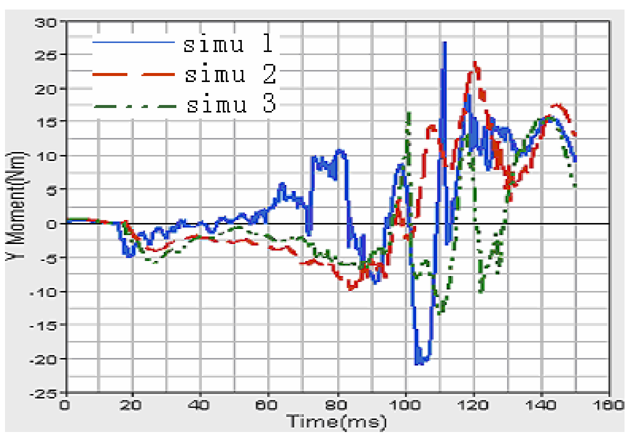


Figure 10: neck Y-direction moment

The neck resultant forces of three models are shown in Figure 8. Figure 9 show the neck forces in Z-direction. The neck moments in Y-direction are shown in Figure 10. As were expected, the neck loads were reduced when used booster cushion and booster seat.

4. Discussion

Initial position of dummy influenced the initial acceleration of pelvis greatly. The dummy was positioned through an equilibrium simulation. However, even after this equilibrium, the dummy's pelvis exhibited unrealistic accelerations at the beginning of the crash simulations. Hence, more work should be done on both dummy initial position and contact definitions.

The routing of shoulder belt influenced the neck loads, chest accelerations and then head accelerations. The interaction between shoulder belt and neck influenced the time and intensity of head acceleration peaks. The positioning of lap belt influenced the pelvis accelerations. It indicates that initial positioning of safety belt is very important.

When used only three-point adult seat belt, upper limb of dummy was restrained by shoulder belt. This was one of reasons that caused higher head accelerations and chest accelerations. The use of boosters avoided upper limb being restrained and reduced the head accelerations and chest accelerations.

The friction coefficient between boosters and vehicle seat influenced the head accelerations and chest accelerations greatly. It indicates that it is very important to reduce the relative motion between boosters and vehicle seat.

The parameter values changed abruptly at near 0.015s in all curves. It could be because the pretensioner was activated and the surface of dummy was rigid, then caused safety belt loads to increase abruptly. Whereas, in physical tests safety belt can penetrate the cloth or rubber skin of dummy and safety belt loads increase gradually.

This paper modeled buckle pretensioner and didn’t model load limiter in safety belt system model. In the next works, retractor pretensioner and limiter can be modeled.

The MADYMO model of Hybrid-III 6 years old dummy is designed for the Out of Position (OOP)airbags studies and not for seats and restraint systems tests. This could explain the unrealistic motion of the pelvis observed in the simulation results, as well as the instabilities in many of the signals got from the simulation. Consequently, referring to the conclusions and datum in this paper should be with caution.

5. Conclusions

In front impacts using booster cushions and booster seats have almost equal effectiveness on reducing head accelerations, chest accelerations and neck loads of the dummy model. But chest accelerations had a little increase when used booster cushions than booster seat. It indicates that using booster cushions can have higher chest injury risk than booster seats in front impact.

When used booster cushions and booster seats, head accelerations, chest accelerations and neck loads had a great drop. It indicates that using booster cushions and booster seats can minimize the injury risks or mitigate injuries of child occupants in frontal impacts.

Reducing relative motion between boosters and vehicle seat can minimize the injury risk of child occupants.

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