African Journal of Management Engineering and Technology

Afr. J. Manag. Engin. Technol., 2024, Vol. 2, N° 1, 41-50

Development of Child Restraint Seat Finite Element Model

Ibrahim A. Rafukka

Department of Mechanical Engineering, Faculty of Engineering, Bayero University, PMB 3011, Kano, Nigeria
Email: ibrahimrafukka@yahoo.com
Phone number: +2348038749657

Received *02 June 2024,*
Revised *03 July 2024,*
Accepted *04 July 2024*

Keywords:
- ✓ *Child dummy;*
- ✓ *Crash analysis;*
- ✓ *Child restrain seat;*
- ✓ *Finite Element Model;*
- ✓ *Vehicle safety ;*

Citation: *Rafukka I. A., (2024) Development of Child Restraint Seat Finite Element Model, Afr. J. Manag. Engg. Technol., 2(1), 41-50*

Abstract: Child seat is a main safety feature in vehicle, meant to protect infants and toddlers in car accident in order to reduce the impact loading transferred to the child occupant in crashes. Virtual crash simulations remain the only tool to optimize safety performance of vehicles at design stage. Crash dummy and vehicle models are created by reverse engineering techniques for application in crash simulations. A restrained child seat Finite Element (FE) model that fits child anthropometry is also required for the crash test. This paper presents the FE modelling of Three Year Old (3YO) child Bebe-confort seat using anthropometric data of 3YO Nigerian child. The CAD model was produced using CATIA software and meshing is done in LS Prepost. The material properties of the child seat frame, belt and foam were extracted from the Bebe-confort seat. Validation was carried out using experimental data of 3YO Hybrid III (HIII) dummy sled test. The response of the dummy in the child seat FE model qualitatively corresponds well with experimental results and the acceleration time history was also comparable to HIII dummy. Child seat FE model could be used in crash simulations for child vehicle safety.

1. Introduction

Child safety in vehicles crash is an issue of serious concern to auto makers. Safety systems such as airbag and seat belt are designed for adult occupant protection against injury in vehicle crash. They are not suitable for young children because of size and biomechanical response differences (Burdi *et al.* 1969; Huelke, 1998). Crash analysis is conducted on car FE model at design stage to ensure safety performance of vehicles (Yang et al., 2000). This reduces cost of production and allows for optimization of safety features and crash components before the vehicle is produced (Sai Kiran *et al.* 2017; Idrees *et al.*, 2023). Child Restrain Seat (CRS) FE models are used in conjunction with the child dummy FE model in crash simulations. This allows for evaluation of safety performance of the CRS and vehicle structures as described recently (Rafukka, 2023).

Vehicle FE model are developed by Auto makers and made publically available for researchers. However, limited number of CRS FE model are available in the literature and these include seat model for toddlers and infants (Monclus-gonzalez & Eskandarian, 2001), CRS model in MADYMO code for 12-months and three year old for aerospace application (Patil, 2003), deformable child seat for three years old in LS-DYNA (Wang et al., 2007), three year old child seat with 3-point harness (Park & Yoo, 2010), and a detailed child seat which is validated based on test data for side impact (Baranowski & Muszyński, 2015). Jiang, (2022) developed a child FE seat using ergonomics and morphological elements that meets the needs of children based on structural design. These CRS FE models were developed based on reverse engineering process and are mainly produced either for dynamic analysis of CRS on impact or for studying the effect of CRS parameters on child occupant injury on crash event.

It is clearly shown in the mentioned studies that one of the major problem of CRS is using incorrect seat for child of a given height and weight. The design of CRS has to meet safety standards of a particular country or region, which is established according to the type of vehicle used as well as the anthropometry and biomechanical characteristics of children occupants of the particular population. Thus, there is need to develop a child seat FE model that fit the size of child occupant. The aim of this work is therefore to develop and validate FE model of CRS that fits Nigeria three year old child. CRS FE model could be useful in child safety crash simulations of cars produced in Nigeria and if constructed, the child seat would be locally available for users and this will encourage Nigerian citizens in using CRS for vulnerable population, thus, reducing child fatalities in vehicle crashes.

2. Methodology

Convertible child seat commonly used to restrain children in vehicle was used in this work. It includes the basic features such as one piece-modelled shell seat with side wings, foam pad insert and five point harness belt. The seat geometry was obtained from commercial seat dimensions available in the literature (Serre et al. 2005), called BEBE CONFORT child seat which has combined booster with five point harness made for toddlers and child up to 36 kg as shown in Figure 1. Dimension for 9-18 kg was utilized in this study. It was made in Europe and has a side impact protection feature.

Figure 1 Bebe confort child restraint seat (Dorel, 2014)

Child seat dimensions as measured by Serre et al. (2005) are presented in Table 1.

Table 1 CRS dimensions in mm

1	Seat cushion depth	412
2	Seat cushion depth from anchorages point	230
3	Seat cushion width	280
4	Seat cushion height	130
5	Seat height	521
6	Maximal height of the belt position	290
7	Armrest height	154
8	Armrest depth	220
9	Anchorage width	75
10	Anchorage height	85
11	Maximum lateral distance for the thigh	94
12	Anchorage of the two seat belts width	112

Some adjustments were made for the width to effectively accommodate 50^{th} percentiles 3YO Nigerian child dummy model. The anthropometric data used for the seat modelling is presented in Table 2, (Rafukka *et al.* 2016):

Table 2 Anthropometric dimensions

Dimension	**50^{th}Nig. Child (Male &Female) (cm)**
Neck breadth	8.5
Neck circumference	23.0
Neck length	4.0
Chest breadth	16.0
Chest depth	12.3
Chest circumference	49.3
Shoulder height seated	31.0
Shoulder breadth	22.1
Shoulder depth	20.5
Shoulder to elbow	16.0
Back of elbow to fingertip	22.6
Waist breadth	16.0
Waist circumference	45.9
Rump to knee length	22.8
Knee to sole length	22.5
Foot length	14.0
Foot breadth	7.0

The following steps were followed in child seat modelling:

- Extraction of seat geometry
- Preparing the child seat computer aided design (CAD) model with LS-PrePost (2024 R1 4.11).
- Meshing the CAD model
- Defining the materials, sections and thicknesses
- Conducting convergence test for stability
- Validating the child seat

The seat and belt CAD model were drawn and meshed using LS-PrePost. It contains 3552 nodes, 3436 quadrilateral and 32 triangular elements. Figure 2 and Figure 3 show the CAD and assembled meshed child seat respectively.

Frontal view Right view

Figure 2 Child seat CAD model

Figure 3 Assembled meshed child seat

The CRS was modelled using rigid material model as it is assumed not deform under child weight. The mesh quality was tested and the aspect ratio and warpage angle were 4.92 and 8.74^0 respectively. Polypropylene material properties with Belytschko-Tsay shell elements were used for the seat. Fabric material (material type 34 in LS-DYNA) with isotropic properties also with Belytschko-Tsay shell element was applied for five point harness belt. Both the seat and belt was modelled using 2mm thickness membrane elements. The material properties are presented in Table 3.

Table 3 Material properties of child seat and belt (Kapoor *et al.* 2006)

Parameter	Child seat	Five point harness
Density (kg/m^3)	900	911.8
Elastic modulus (GPa)	1.2	6.27
Poisson's ratio, ϑ	0.3	0.3

In order to reduce computation time, the seat was simplified to three parts: rigid seat, five point harness belt and the pad for child comfort. The child rigid seat was covered with a foam pad at areas where dummy made contact with it in order to simulate the effect of foam in the CRS that provides comfort to the child. The deformable foam was modelled using solid element. Material type 57 (MAT_LOW_DENSITY_FOAM) was applied to model the foam as was done by Li *et al.* (2016). Material properties were obtained experimentally from automotive seat foam and were used to model child seat and car deformable seat foam in (Patten *et al.*, 1998; Wang *et al.*, 2007; Pan-Zagorski *et al.*, 2022;). The foam elastic modulus and density were taken as 5.463 MPa and 50.2 kg/m^3 respectively. The hysteresis unloading factor and shape factor were assigned to be 0.1 and 5 respectively. Stress -strain curve for the foam is shown in Figure 4.

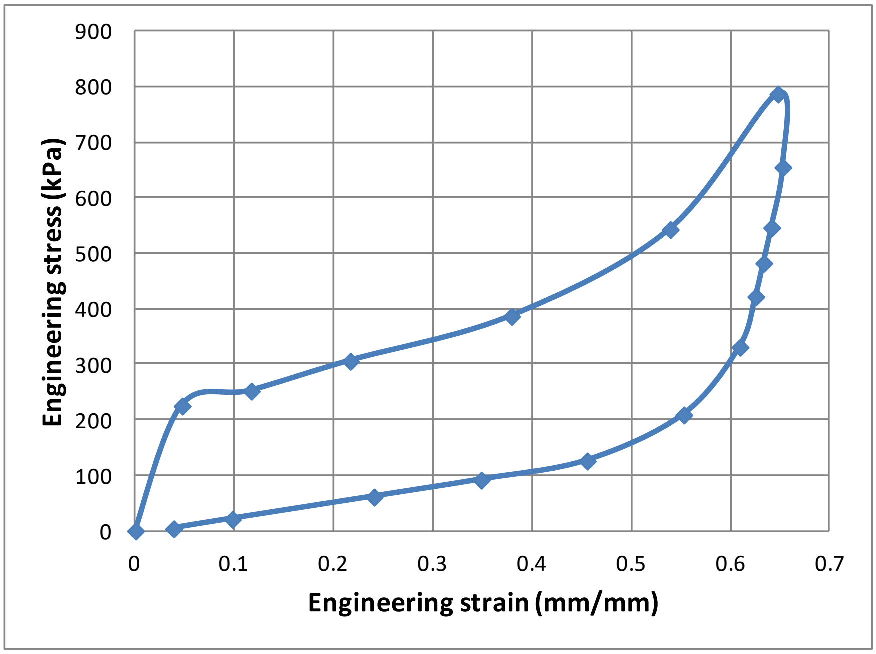

Figure 4 Stress-strain curve for CRS foam pad (Wang et al., 2007)

The foam was made up of 4432 solid under integrated elements. Minimum time step of the model is controlled by setting the parameters like the minimum length of element which is related to the characteristic length and the number of triad, to be within some allowable range. Triad used to be stiff as such it needs to be less than 5% in the model. Table 4 presents the mesh quality criteria of the CRS model. Percentage of parameters violating criteria is relatively small, hence the model was considered as stable.

Table 4 Mesh quality of child seat FE model

Parameter	Min/max values	Allowable Max	% violating criteria
Minimum element length	3.5/12.9	10.9	0.6
Maximum element length	6.5/22.8	108.6	0
Warpage angle	0/25.8	10	0.102
Jacobian	0.444/1	0.6	0.132
Aspect ratio	1/3.34	10	0
skew	0/33.2	45	0
Minimum quad angle	37.2/90	45	0.0796
Maximum quad angle	90/157	135	0.0796
Minimum triad angle	20.5/59.1	30	0.0455
Maximum triad angle	60.7/95.9	120	0

To ensure that the CRS model represents the three year old child seat, a validation was carried out by simulating a sled test and comparing the head and chest acceleration with results obtained from literature (Turchi et al. 2004).

3. Results and Discussion

3.2 Child Seat validation

The performance of the seat was evaluated using experimental test conducted by Turchi et al. (2004). The child seat developed was assessed by simulating sled test based on the FMVSS 213 specification acceleration pulse. Figure 5 shows the response of crash dummy FE model (D_{Nig}) in CRS as compared with 3YO HIII dummy response in physical CRS.

The response of the D_{Nig} qualitatively correlates with the biomechanical response of physical 3YO HIII child dummy. This is an indication of the ability of the CRS FE model to provide restrain to D_{Nig} that simulate the physical CRS.

The head and chest acceleration being the parameters used for CRS validation was compared with experimental results of sled test carried out using the physical 3YO HIII child dummy in a standard CRS by Turchi et al. (2004). Figure 6 and Figure 7 compare the head and chest acceleration of the dummy in CRS model.

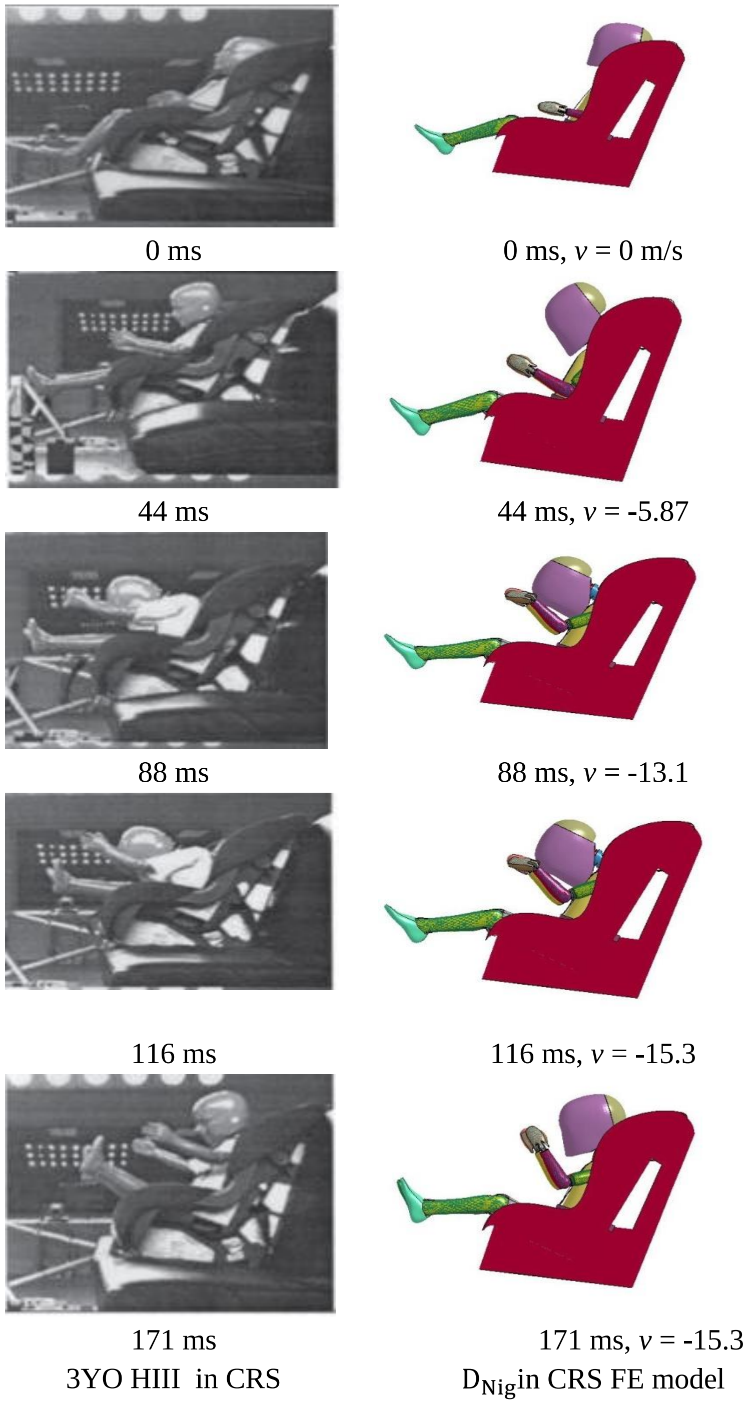

Figure 0 Child dummy ($\mathbf{D_{Nig}}$) response at some instances of sled test in comparison with 3YO HIII child dummy from Turchi et al. (2004)

For the head acceleration, the dummy response shows good correlation with experimental results in terms of curve trend and the occurrence of peak value. There was fair agreement in terms of peak values of head acceleration with a difference of 26%. The differences can be attributed to the dummy characteristics because 3YO HIII physical dummy was used in literature studies while in the present study, the scaled dummy model from 6YO HIII was used. For chest acceleration however, there was good agreement in terms of peak value with a difference of 11.6% as seen in Figure 7. This indicates that the child seat modelled here represents that for a 3YO CRS and can therefore be used to accommodate the D_{Nig} in crash test simulations. The child seat was validated for frontal impact. However, the performance under impact in other directions has not been assessed.

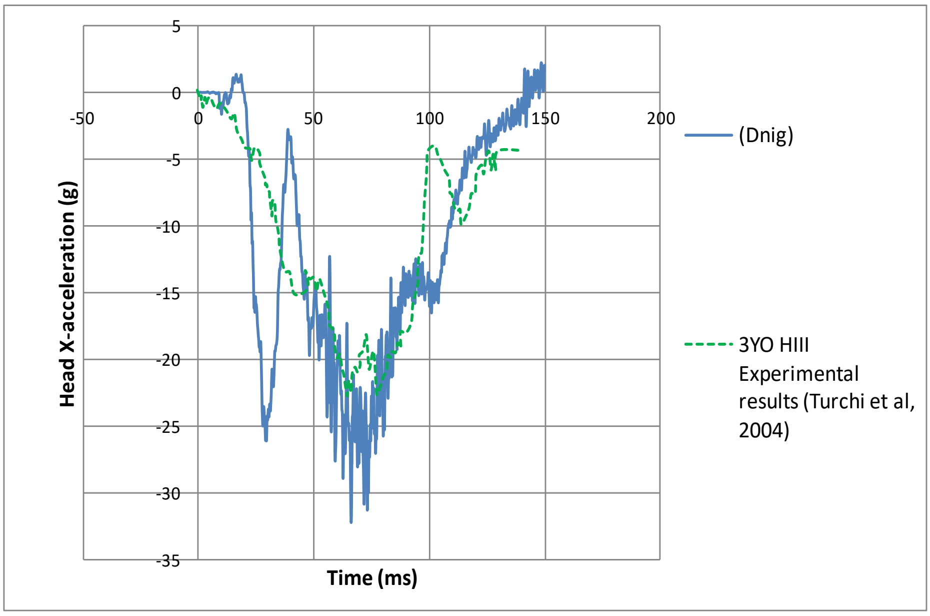

Figure 6 Head acceleration of $\mathbf{D}_{\mathbf{Nig}}$ in CRS in comparison with experimental results

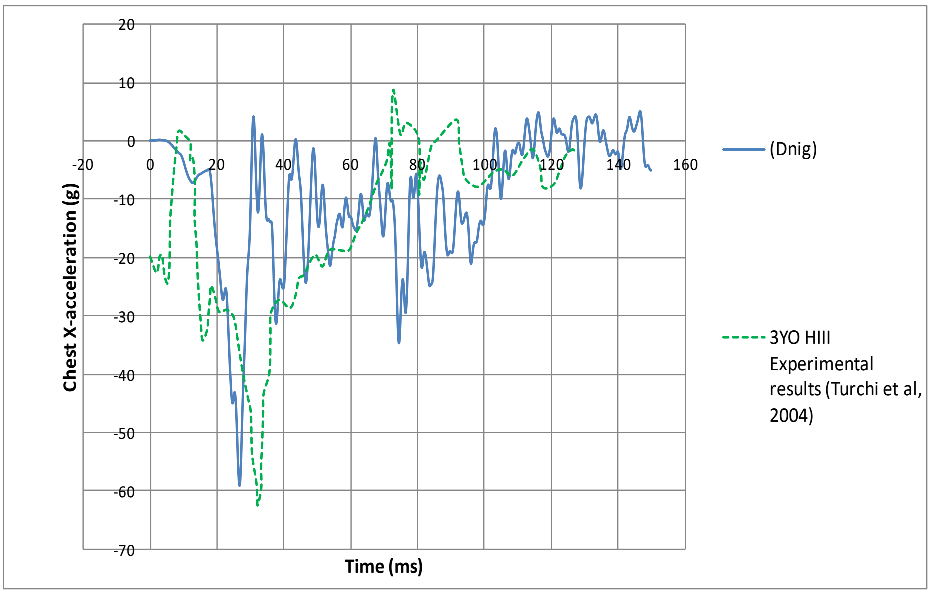

Figure 7 Chest acceleration of $\mathbf{D}_{\mathbf{Nig}}$ in CRS in comparison with experimental results

Conclusion

Child seat finite element model has been developed using 3YO Nigeria child anthropometry. Material properties of the seat parts were experimentally determined and were validated. Mesh convergence test was conducted and it was found that percentage of parameters violating criteria is relatively small and the model was considered stable. CRS FE model restrained the child dummy FE model in similar way the physical CRS restrained the crash dummy because the biomechanical responses of FE model at some instances in the crash simulation were qualitatively identical to HIII dummy. Resultant head and chest acceleration of the dummy restrained in CRS FE model differ by only 26% and 11.6% respectively which further validates the developed child seat. It is recommended that the CRS developed in this study should be used in crash simulations for Nigerian children.

Acknowledgement: The authors would like to acknowledge Bayero University, Kano, Nigeria for the supports in works related to this paper.

Conflict of Interest: The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Baranowski, P., Damaziak, K., Malachowski, J., Mazurkiewicz, L., & Muszyński, A. (2015) A child Seat Numerical Model Validation in the Static and Dynamic Work Conditions. *Archives of Civil and Mechanical Engineering*, *15*(2), 361–375.

Burdi, A. R., Huelke, D. F., Snyder, R. G., & Lowrey, G. (1969), Infants and children in the adult world of automobile safety design: pediatric and anatomical considerations for design of child restraints. *Journal of Biomechanics*, *2*(3), 267–280.

Dorel, J., (2014) Bebe confort trianos combination booster car seat. Retrieved July 1, 2016, from http://www.bebeconfort.com/car-seats/trianos.aspx

Huelke, D. F. (1998) An overview of anatomical considerations of infants and children in the adult world of automobile safety design. *Annual Proceedings of the Association for the Advancement of Automotive Medicine*, *42*, 93–113.

Idrees I., Ahmad S., Shah I. A., Talha M., Shehzad R., Amjad M., Rahiamin Koloor S. S. (2023), Finite element analysis of car frame frontal crash using lightweight materials, *Journal of Engineering Research*, 11(1), 100007, ISSN 2307-1877, https://doi.org/10.1016/j.jer.2023.100007

Jiang, X. (2022) A Structural Design of a Child Seat Based on Morphological. *Computational Intelligence and Neuroscience*, *2022*.

Kapoor, T., Altenhof, W., Wang, Q., & Howard, A. (2006) Injury potential of a three-year-old Hybrid III dummy in forward and rearward facing positions under CMVSS 208 testing conditions. *Accident Analysis and Prevention*, *38*, 786–800.

Li, X. G., Gao, X. L., & Kleiven, S. (2016) Behind helmet blunt trauma induced by ballistic impact: A computational model. *International Journal of Impact Engineering*, *91*, 56–67. http://doi.org/10.1016/j.ijimpeng.2015.12.010

Monclus-gonzalez, J., & Eskandarian, A. (2001) Development of Detailed Finite Element Models of Child Restraint Systems for Occupant Protection, In *17th ESV Conference Paper* (pp. 1–10).

Pan-Zagorski W., Johnson P. W., Pereny M., Kim J. H. (2022) Automotive Seat Comfort and Vibration Performance Evaluation in Dynamic Settings. *Applied Sciences*. 12(8), 4033. https://doi.org/10.3390/app12084033

Park, D. W., & Yoo, W. S., (2010) A study on the design of a child seat system with mutipoint restraints to enhance safety, *Journal of Mechanical Science and Technology*, *23*, 3316–3322. https://doi.org/10.1007/s12206-009-0922-2

Patil, A., (2003) *Modeling and Evaluation of Child Safety Seat and Restraint System for Aerospace Application*. Wichita State University.

Patten W.N., Sha S., Mo C. (1998), A vibrational model of open celled polyurethane foam automotive seat cushions, *Journal of Sound and Vibration*, 217, Issue 1, 145-161, ISSN 0022-460X, https://doi.org/10.1006/jsvi.1998.1760

Rafukka, I. A., Sahari, B. Bin, Nuraini, A., & Manohar, A. (2016) Anthropometric Comparison of Three-Year-Old Nigerian Child and Crash Dummies, *Journal of Transportation Technologies*, *6*(4), 192–199.

Rafukka I. A. (2023) Numerical Evaluation of Injuries to Unrestrained Six Year Old Child Passenger in Vehicle Frontal Crash Test, *Afr. J. Manag. Engg. Technol.*, 1(2), 120-127

Sai Kiran C., Sruthi J. and Chandrahas Balaji S. (2017) Design and Crash Analysis of a Passenger Car using ANSYS Workbench, *CVR Journal of Science and Technology*, 13, 96-100

Serre, T., Lalys, L., & Lecoz, S. (2005) Anthropometric data of the 3 and 6 year-old child regarding the position of the safety belt, *Digital Human Modeling*, 1–8.

Turchi, R., Altenhof, W., Kapoor, T., & Howard, A. (2004) An investigation into the head and neck injury potential of three-year-old children in forward and rearward facing child safety seats. *International Journal of Crashworthiness*, *9*(4), 419–431.

Wang, Q., Kapoor, T., Tot, M., Altenhof, W., & Howard, A. (2007) Child restraint seat design considerations to mitigate injuries to three-year-old children in side impact crashes, *International Journal of Crashworthiness*, *12*(6), 629–644.

(2024) ; https://revues.imist.ma/index.php/ajmet/index