Proceedings of the 12th International Forum of Automotive Traffic Safety, 2015, pp 233- 238
No. ATS.2015.S3A12

Virtual Evaluation of Headrest Geometry on C-NCAP Whiplash Injury Outcomes

ChengyueJIANG[1], Xi LIU[1], Dong CUI[2], YuanzhiHU[1]

[1]*Chongqing University of Technology, Chongqing, China,400054*

[2]*China Automotive Technology and Research Center, Tianjin, China,300300*

Email:liuxi@cqut.edu.cn

Abstract:

***Background*:**The injury outcomes in whiplash sled test are correlated to test severity as well as the seat restraint. A well designed and correctly aligned head restraint can vastly reduce the risk of injury to the head, spine and neck during the rear-end collisions. For the safety issue, it is essential to know how sitting position and headrest geometry parameters affect the occupant kinematics and the related injury index in rear-end collisions.

***Objective*:**This paper is aimed to evaluate the protective performance of different headrest geometry parameters (including the height and horizontal distance), based on a validated C-NCAPwhiplash sled test simulation model.

***Method and Material*:**A virtual MADYMO simulation model with the BioRID II dummy was built up and correlated with a sled test to ensure the accuracy and comparability of the virtual model. Based on this baseline model, the headrest geometry parameters including the height and horizontal distance were evaluated.

***Results*:**The study indicates that headrest geometry parameters have significant effects on both dummy kinematics and the related injury index, the NIC value could be reduced by 31%, while the upper neck My index could be improved by 15% in this case study.

***Conclusions*:** Virtual simulation is efficient to evaluate the headrest design change's effect on dummy kinematics and injury results.By evaluating the NIC index and other neck injury results from the virtual sled simulations, the optimal seat headrest design was proposed.For further validation of the research results, sled test of the optimal case is highly recommended.

Keywords: Whiplash injury, Headrest geometry, MADYMO, Virtual evaluation, C-NCAP

1 Introduction

Whiplash is an injury of the cervical spine soft tissue, caused by the sudden acceleration of the head relative to the torso, which occurs during a rear-end collision, mostly occurring at low impact velocities, typically less than 20 km/h [1,2].The risk of sustaining whiplash injury in rear-end collisions has been shown to be related to collision severity as well as occupant restraint status [3,4]. In general, with increasing collision severity, there is an associated increase in the risk of sustaining injury. Many of the previous studies focus on the risk of neck injury and the role of the seat parameters (such as seatback stiffness, head restraint geometryetc.) on the injury potential for occupants in rear-end collisions [5]. A well designed and correctly aligned head restraint will vastly reduce the risk of injury to the head, spine and neck during rear-end collisions [6]. Head restraint geometry, specifically head restraint height and horizontal distance ‘setback’ of the head restraint from the occupant’s head can have a significant influence on the likelihood and severity of a whiplash injury in rear impact collisions [7].

Driver studies show that many vehicle occupants do not adjust their car seats to the most appropriate setting for optimal protection. Furthermore, vehicle occupants position themselves differently in the seat which leads to a vast variety of seated positions. For the safety issue, it is essential to know how sitting position and headrest geometry parameters affect the occupant kinematics and the related injury indexin rear-end collisions.

Therefore, the aim of this study was to evaluate the protective performance of different headrest geometry parameters (including the height and horizontal distance), based on a validated C-NCAP[8] whiplash sled test simulation model. By evaluating the NIC (Neck Injury Criterion) index and other neck injury results from the MADYMO simulation models, the optimal seat headrest geometry parameters for whiplash prevention and the improvements were obtained.

2 Method

In this study, both experimental and virtual methods have been used for the whiplash injury simulation and evaluation. Firstly, a CAE (Computer Aided Engineering)virtual sled test with the BioRID II dummy was built up and correlated with a real physical whiplash test to ensure the accuracy and comparability of the virtual simulation model.

Secondly, the headrest geometry parameters and the relative simulation matrix were defined based on the test results and literature review. The CAE virtual model which complies with the C-NCAP whiplash test protocol was used in virtual sled tests to identify the influence of headrest geometry on the BioRID II dummy kinematics and injury index.

Finally, based on the results of the virtual tests, the evaluation work was carried out. This step was performed to analyze the detailed effects of the headrest geometry, and to obtain the optimized seat headrest geometry parameters for whiplash prevention.

3 Virtual model and evaluation

3.1 Virtual sled test model

In this study, MADYMO Version 7.5[9] was used for the following virtual simulations. The main systems of the finite element simulations include seat model (the seat model development work was mainly contributed by a local OEM) and the BioRID II dummy model from the dummy database. Both seat model and the integrated sled model are shown in Fig 1, as follows.

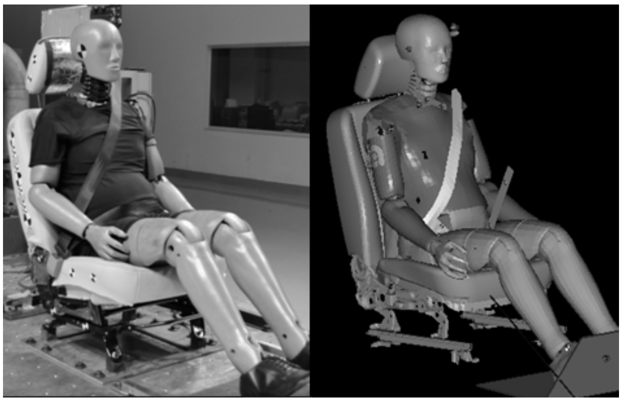

Fig1: Whiplash sled test (left) and the virtual sled test model (right)

3.2 Virtual model correlation

The correlation work of the virtual model was mainly carried out in the MADYMO circumstance (version 7.5). In this study, the sled test pulse, as shown in Fig 2, was introduced into the MADYMO model to drive the sled and seat model.

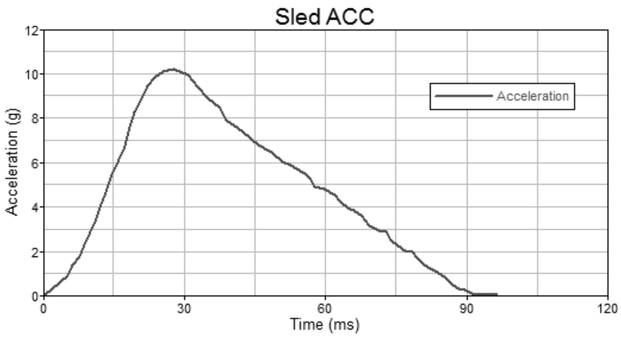

Fig2: Whiplash sled test acceleration

The model validation work was mainly about the dummy positioning, FE-FE contact characteristics definition, as well as the joint restraint correctionetc. The simulation result indicates that the head acceleration of virtual model correlates well with that of the physical sled test, see the Fig3 below.

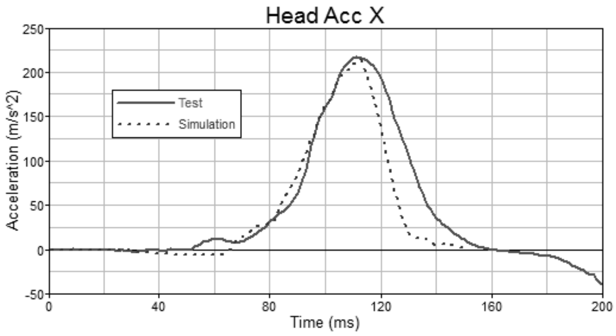

Fig3: Correlation ofhead acceleration

Although the NIC peak value of simulation model is a little different with that of the physical test, the trajectories of both curves fit good, as shown in Fig4.

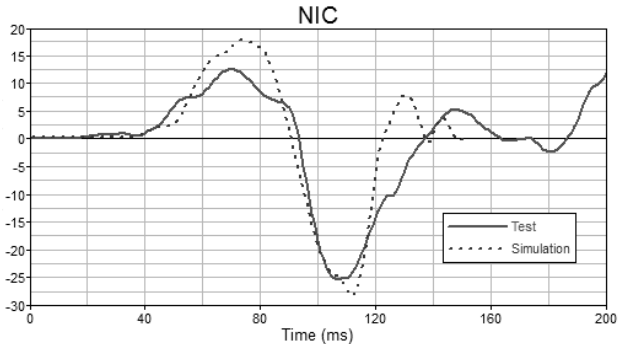

Fig4: NIC index correlation

Figure5 shows the comparison of BioRID II dummy kinematics of physical test and simulation at different time steps, which ensures the accuracy and comparability of the virtual model.

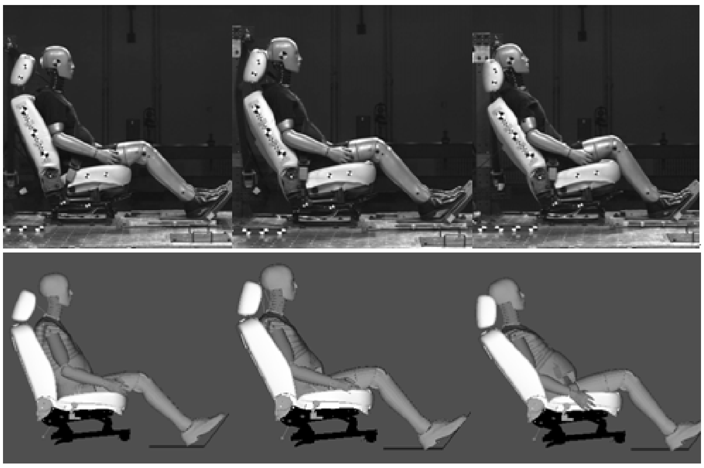

Fig5: Comparison of dummy kinematics of test (upper row) and simulation (lower row) at 0ms, 60ms and 100ms

3.3 Headrest geometry evaluation

In this study, the main purpose is to evaluate the headrest positioning parameters' effects on the BioRID II dummy kinematics and injury index. Thus, headrest geometry parameters (including the height and horizontal distance, based on literature review) and simulation matrix were defined, as shown in Table 1.

Table 1: Headrest geometry set-up and simulation matrix

N0.	Forward position	Upward position
Case1	0mm	0mm
Case2	0mm	20mm
Case3	0mm	40mm
Case4	20mm	0mm
Case5	20mm	20mm
Case6	20mm	40mm

Note: case1 is the base run.

Take case1 and case6 as examples, the main difference of these two models is the headrest position, as shown in Fig6. The headrest position of case6 is 40mm upward and 20mm forward.

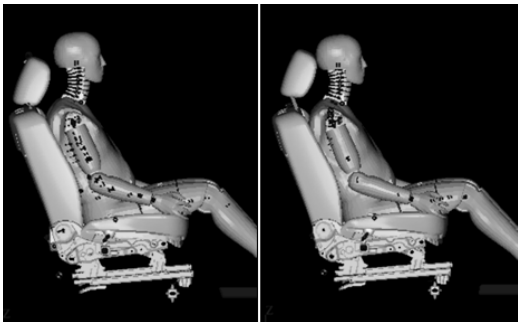

Fig6. Illustration of headrest position of case1 (left, original design) and case6 (right)

According to the NIC simulation results, this injury index is quite sensitive to the headrest geometry. The NIC score was improved by 31%, when comparing case4 with case1, as shown in Fig 7.

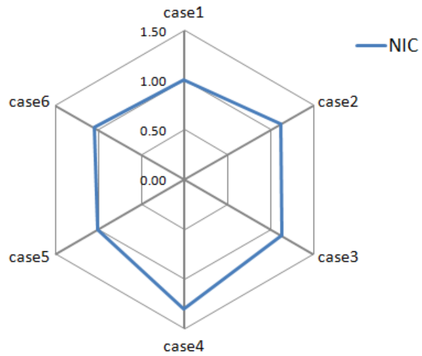

Fig7. NIC index comparison

The simulation results also indicate that all the upper neck extension forces of case2,case3, case5, case6 are less than 475N, which can get 1 point according to C-NCAP protocol (full mark), as shown in the Fig 8 below. When remain the upward position at 0mm, there is little improvement of the upper neck extension force (see case4 and case1).

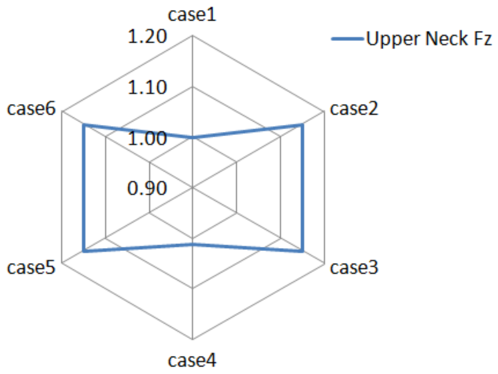

Fig8. Upper neck extension force comparison

When evaluating the upper neck moment of these virtual simulations (Fig9), the simulation results indicate that keep the headrest's front and rear position unchanged and move the headrest upward can significantly improve the upper neck My score in this case. The upper neck My score was improved by 15% in this study, when comparing case3 with case1.

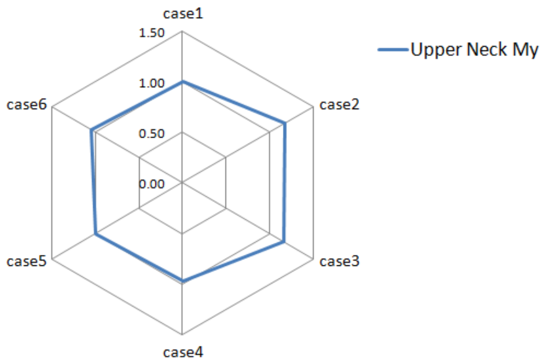

Fig9. Upper neck moment comparison

Comparing all these simulation results above, case3 gets the highest score according to the C-NCAP test protocol. The whiplash score of case3 is 0.37 point higher than that of case1 (original design). The head and neck kinematics of case1 is a little different with that of case3 as well, see Fig 10 below. In case3, the seat headrest hold the dummy head well immediately after the head-seat contact, which reduces both the upper neck extension force and moment.

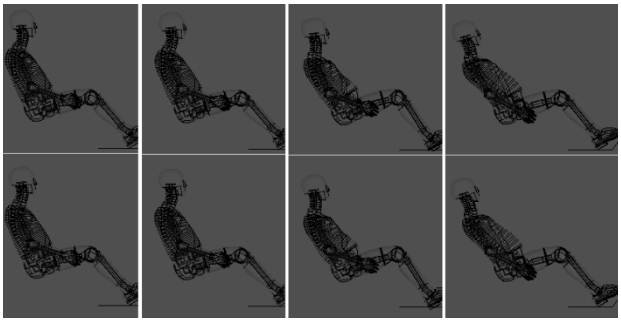

Fig10. Comparison of dummy kinematics of case1 (upper row) and case3 (lower row) at 0ms, 40ms, 80ms and 120ms

4 Conclusions and discussions

In this study, a virtual sled test model was built-up and correlated with the physical test, for the purpose of headrest geometry evaluation. According to analysis above, the following conclusions can be drawn:

1): Whiplash virtual simulation is efficient to evaluate the design change's effect on dummy kinematics and injury results.

2): The headrest geometry parameters have significant effects on whiplash injury index. In this study, the NIC value could be improved by 31%, while the upper neck Myindex could be improved by 15%.

3): The optimal parameters could be obtained through simulation matrix and further analysis.

For further validation of the research results, sled test of the optimal case is highly recommended. Besides, further study will be carried out on multi-factor's effects on whiplash injuries and dummy kinematics.

Acknowledgement

This project is supported by National Natural Science Foundation of China (Grant No. 51405050) and Chongqing Science and Technology person training program (cstc2013kjrc-qnrc60002). The authors would also like to thank TASS China for offering the MADYMO educational license.

References

[1] Howard R., Harding R., and Krenrich S. *The biomechanics of "Whiplash" in low velocity collisions*. International Body Engineering Conference and Exposition. 1999. Detroit, USA.

[2] Deng B., Begeman P., Yang K., Tashman S and King A. *Kinematics of human cadaver cervical spine during low speed rear-end impacts*. In the 44th Stapp Car Crash Conference. 2000. Atlanta, USA.

[3] Galli R and Digges K. *Severe head and neck injuries in NASS rear impacts*. SAE Technical Paper 2008-01-0190, 2008.

[4] Edwards M., Parenteau C and Viano D. *Front-seat occupant injuries in rear impacts: analysis of the seatback incline variable in NASS-CDS*. SAE Technical Paper 2009-01-1200, 2009.

[5] Viano D. *Role of the seat in rear crash safety* [M]. SAE International, 2002.

[6] Insurance Institute Highway Safety. *Head restraint can protect our necks*. Insurance Institute Status Report. 2001 36(9).

[7] Acar M., Clark S and Crouch R. *Smart head restraint system*. Int. J. Crashworthiness 2007. 12(4): p. 429-435.

[8] China Automotive Technology and Research Center. C-NCAP test protocol. 2015.

[9] TNO. MADYMO model manual version 7.5. 2014.