Study on Rear Row Occupant Injury and Seat Optimization Based on C-NCAP Whiplash Test Method

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Abstract: In the field of whiplash test, there was a lack of regulations for evaluating the protective performance of rear seats. Referring to the C-NCAP front seat whiplash test method, this paper conducted the rear seat whiplash tests of 10 different models. The test results were presented. The reasons for the loss of NIC, Upper Fz and Upper My were analyzed. The optimization methods of the headrest were discussed and suggestions on the optimization of rear seats were put forward.

1. Introduction
With the increase in vehicle ownership, rear-end accidents have increased year by year [1]. In all kinds of traffic accidents, rear-end accidents account for a large portion of passenger injuries [2]. In the United States, whiplash injury, the neck injury caused by rear-end collision, becomes one of the most common insurance items [3-4]. In 2007, the insurance indemnity of body injury led by rear-end collision reached 8.8 billion dollars, accounting for 25% of the total compensation for traffic accidents [5]. Additionally, based on the traffic accident statistics recorded by ITARDA, 30% of the traffic accidents were caused by rear-end collision in Japan in 2003 [6]. The claim ratio of neck injury has reached 40% [7]. Therefore, it is seen that not only the incidence of rear-end collision is high, but also the probability of neck injury of human is high, thus creating the heavy burden for the individuals and society.

Presently, each country has relevant requirements and standards for the protection of head and neck injuries in front seats in the Whiplash test. However, the evaluation for the neck injuries in back seats is missing and only Europe E-NCAP has the evaluation criterion of static parameters [8]. The seating rate of back seats of vehicle in China is relatively high and the total number of occupants involved in the back row exceeds the number of co-pilots in every hundred accidents with heavy injuries according to the data provided by CIDAS. Therefore, in the evaluation system of Whiplash test, it is necessary to study the injury mechanism of human in the back rows and increase relative evaluation standards. However, in present, China has no relevant evaluation rules concerning neck injury prevention of back rows. Based on that, this paper carried out the research regarding the Whiplash test of back rows.

2. Experimental methods
Whiplash test of back rows was carried out in the white body of cat and its main adjusted status of seats was shown in Table 1. The experiment was divided into two parts, including static measurement and dynamic collision. In static measurement, the H point position of man, posterior head space, head...
pillow height, trunk angle and other parameters were measured. In the dynamic collision, the BioRID II dummy was adopted, whose placement method was basically the same as the Whiplash test method of front rows. The target value of point H of dynamic dummy is located in the area 20mm in front of the static measurement point H and the head space of dynamic dummy is the sum of the result of static measurement and 15mm. In the seats of the back rows, the terrible situation occurs in the torso angle of the dummy. Therefore, during the process of placing dynamic dummy, the target value of the pelvic angle of dummy is the sum of the measured value of torso angle and 1.5°. In the test, the waveform is CNCAP2018 Whiplash test waveform, the peak value of accelerated velocity is 11g and the maximum speed is 20km/h, as shown in Figure 1 [9].

### Table 1. Seat position adjustment status

| Seat status | Slide track | Seat height | Backrest Angle | Headrest Height |
|-------------|-------------|-------------|----------------|-----------------|
|              |             |             | Design Position | Design Position |

![Figure 1. Pulse of rear seat whiplash test](image)

### 3. Experimental results

#### 3.1 Overall situation

In the research, the seats of back rows (the second back rows) in ten different vehicle models were selected to carry out the experiment. The overall static measurement parameters are shown in Table 2. In the dynamic test, each parameter was evaluated based on the CNCAP2018 Whiplash test evaluation method, whose scores were shown in Table 3. The scores of Whiplash test in the back rows of the ten different vehicle models are within the range of 0.5-3.3. In the Whiplash test of back rows, the lose points items of dummy mainly include NIC, upper neck Fz and upper neck My.

### Table 2. Parameters of static measurement

| Parameter | Backset(mm) | Headrest Height(mm) | Torso Angle(°) |
|-----------|-------------|---------------------|-----------------|
| Range     | 50-80       | 60-90               | 25-28           |

### Table 3. Scores of each parameter

| Score | NIC | Upper Fx | Upper Fz | Upper My | Lower Fx | Lower Fz | Lower My |
|-------|-----|----------|----------|----------|----------|----------|----------|
|       | 0 -0.85 | 1.45-1.5 | 0.25-1.5 | 0.3-1.3  | 0.22-1.5 | 1.32-1.5 | 0.79-1.5 |

#### 3.2 Scores of main parameters

##### 3.2.1 Score of NIC

The NIC in the Whiplash test refers to the nerve injury and its specific manifestation is the pain in the nerve root, whose calculation formula was shown in formula 1. In those ten vehicle models, the NIC values are within the range of 0-0.85, the scores of which are relatively low. Figure 2 is the relation schema between accelerated speed of the head of car, accelerated speed of the chest of dummy and NIC. From figure, it is seen that before collision, the accelerated speed of dummy chest increases quickly and reaches the higher level. The variation tendency of the accelerated speed of dummy head is similar to that of dummy chest. After the dummy head collides with the headrest, the accelerated...
speed increases quickly. Compared with the seats in front rows, the backrest of back seat is basically not backwards. Therefore, after collision, it has following characteristics:
The accelerated speeds of head and chest increase rapidly.
The posterior clearance is large, but the contact time is earlier.
In general, the second collision (the head collides with headrest, separate and then collides again) is not obvious.

\[ NIC(t) = 0.2A_{x}^{rel}(t) + [V_{x}^{rel}(t)]^2 \] (1)

Where \( A_{x}^{rel} \) represents the relative acceleration of head and chest; \( V_{x}^{rel} \) represents the relative speed of head and chest.

![Figure 2. The relationship between acceleration and NIC](image)

3.2.2 Score of upper neck Fz
The upper neck of dummy Fz refers to the tensile and compressive forces on the neck of the dummy during collision and the positive value represents stretching while negative value represents compressing. In the diagnostic test, the peak values of the upper neck of ten vehicle models are within the range of 0.25-1.5. The curve of the upper neck of dummy Fz is shown in Figure 3. Compared with the seats in the front rows, the headrest of the seats of the back rows are relatively low, thus making the upper neck of the seats of back rows Fz higher.

![Figure 3. Curve of Upper Fz](image)

3.2.3 Score of upper neck My
The upper neck of dummy My refers to the bending moment of the dummy neck during collision. The positive value represents that the head of dummy is close to the chest while the negative value represents that the head of dummy is away from the chest. Compared with the seats of front rows, the situation of upper upper neck in the seats of back rows is poor. However, unlike the front seats, some parts of the dummy upper neck in the back seat have the negative-score losing situation. The curve of the upper neck of dummy is shown in Figure 4.
4. Discussion about main damage parameters and seat optimization

4.1 Analysis of NIC damage
In the Whiplash test, NIC mainly investigates the consistency of accelerated speed between the head and chest of dummy, that is, when the accelerated speed of head and chest could realize the synchronized motion, NIC has better performance. Compared with the seats in front rows, the skeleton of backrest in back rows is relatively large. In the test, the backrest does not fall back or the angle of dumping is small. Therefore, the backrest of the seats in back rows has poor energy absorption capability, thus leading to the rapidly increasing trend of the accelerated speed of dummy chest at the early time (about 45ms) and the increasing of NIC. Since the backrest basically doesn’t fall back, the contact time between the head and headrest is early (at around 60ms) during collision. After the contact of head and headrest, the acceleration of the head also shows a rapid upward trend while the NIC decreases. Therefore, the peak values (within the range of 70-80ms) of NIC occur at a time when the difference between head and chest acceleration decreases. The range that NIC rapidly increases is within the scope of 45-70ms, which should be focused to improve and optimize. Based on the performance of NIC of the seats in the back rows, we find that under the situation that the skeleton of the seats in back rows is not changed, increasing the energy absorption ability of the backrest foam cushion (reduce the accelerated speed of chest) and decreasing the posterior head space could effectively reduce the peak value of NIC.

4.2 Analysis of injury of upper neck Fz and My
The headrest of the back rows is relatively low and the distance between the highest point of the headrest and the highest point of dummy head is within the range of 60-90mm. In the middle and late stages of the collision, the headrest could not provide effective support to the head, thus making the dummy head collide with the headrest. The stretching of the neck is more obvious. Therefore, the Fz peak value of the seat of front rows is higher than that of the upper neck.

The My in upper neck is mainly caused by the impact of the headrest and head. Due to the poor energy absorption ability of the skeleton in the seats of back rows, during the middle and late period of collision, the impact of the headrest on the head is more severe so that the injury of upper neck My of dummy is more serious. During the optimization of the front seats, modifying the shape of headrest could effectively reduce the peak value of upper neck My. However, under the serious impact, the effect of modifying the shape of headrest is not obvious. Under that situation, the height of headrest could be reduced appropriately to make the impact of headrest on the head reduce during collision, thus reducing the forward torsional trend of the neck of the dummy and achieving the purpose of reducing the My of the upper neck. When the height of headrest is low, the situation that the head of dummy is tilted back occurs since the headrest could not support the head. Therefore, the upper neck My will have a negative loss.

Fully considering the upper neck Fz and My, the height of the headrest in the seats of the back rows should be suitable, thus ensuring that the tension and torque of the upper neck are better protected.
4.3 Discussion of optimization scheme of back seats

Fully considering the injury situation of dummy in the back rows, the seats was optimized. The original state of the seat is that the posterior head space is 57mm and the altitude difference between head and headrest is 50mm. The first step is to improve the height of headrest and reduce the altitude difference to 18mm. The second step is to increase the height of the headrest and reduce the posterior head space to 9mm. The state of the headrest and the scores are shown in Figure 5.

Figure 5. Headrest Status

From the experimental result, it is seen that the improvement effect of the seat is not obvious, which has no obvious improvement in its score, from 3.17 to 3.11 then to 3.24. Compared with the seat in the front rows, the headrest wall of the back seat is thicker and the length of the headrest rod is shorter. Increasing the height of headrest could make the length of headrest rod shorter and headrest lose stability so that the headrest could not provide effective support. From the relation curve of the NIC and accelerated speed of head and chest, it is found that after the contact of head and headrest, the accelerated speed of head increases rapidly. However, after the headrest loses stability, which could not provide effective support, the accelerated speed dose not rise significantly after the accelerated speed of head decreases. At the same time, the accelerated speed of chest is still in the high level and increasing continuously. As the accelerated speed of head and chest as well as the difference of relative velocity increase, the peak value of NIC increases. Therefore, the measures for protecting the performance could not meet the expected effect.

5. Conclusions

Based on the C-NCAP method of Whiplash test in the seats of front rows, this paper carried out the Whiplash test for the seats of back rows of the ten different vehicle models. Additionally, the results of main parameters of static measurement and dynamic test were listed, the injury mechanism of main evaluation parameters was analyzed and the improvement methods of the performance of seat were discussed. The conclusions of this paper were made as follows:

Similar to the seats in front rows, the main score-missing items in the Whiplash test of the seats in back rows include NIC, upper neck Fz and upper neck My.

In the Whiplash test, the effect of second collision of the dummy head is not obvious.

When reducing posterior head space, the strength and stability of headrest rod should be taken into account.

The height of the headrest of the seats in the back rows needs optimizing reasonably, thus protecting the tension and torque of the upper neck.
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