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The Influence of Occupant Grip on Ceiling Handrail and Injury Assessment in Collision

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ABSTRACT

With the rapid increase in the number of cars, to bring a variety of convenience to mankind， at the same time, a number of traffic safety problems also followed, which causing serious injuries and property losses, bring more pain and regret to the people. Therefore, to accurately assess the damage of the personnel in the collision safety accident is very useful to improve the safety performance and functionality of the vehicle. so, the crash dummy plays an important role in the research of crash safety. At present, in the study of human body injury in the collision with dummy, the influence of roof handrails grasping state was not considered. Therefore, the software of LS-PREPOST and Oasys PRIM-ER are used to build model of automobile cockpit and dummy with hand grip ability, the acceleration environment of frontal crash was simulated by adding B-pillar acceleration curve from real vehicle crash test. Comparing injuries of dummies in free sitting posture and holding the roof armrest in collision. he simulation results show that when the dummy was grasping the roof armrest, the peak value of head acceleration and HIC values were 6.1% and 30.2% lower than the dummy was sitting freely, the maximum value of shear force, tensile force and bending moment of the neck were reduced by 87.4%, 76.9% and 42.9% respectively, and the maximum value of chest compression was reduced by 16.9%. The results provide a reference for the research of passive safety in collision.

Keywords: crash safety; crash dummy; roof armrest; LS-PREPOST

INTRODUCTION

The NHTSA (National highway Traffic Safety Administration) reports that there are three types of accidents: frontal collision, side collision and collision. Among the three kinds of collision accidents, head-on collision accidents account for 49%, and the death of occupant for 33.5% of the total death, ranking the first [1]. Therefore, it is particularly important to establish a human -vehicle crash model by finite element technique with digital dummies in the study of crash safety. At present, researchers at home and abroad have done a lot of study on collision safety using digital dummies. Manulmendoza. Vazquez et al. used the THUMS finite element dummy model to analyze the chest injury of passengers under frontal collision, and established an injury risk curve that could predict and determine the degree of chest injury through the simulation results [2]. Gernot Woitch et al. used digital dummy model to study the occupant injury under the work of active safety system in collision [3]. Lee K W et al. analyzed the injury of 5 percentage female dummies in the co-pilot position during the frontal collision [4]. Domestic scholars have also done a lot of research in this field. Luo Tanyue et al. studied the chest injury of passengers under frontal collision of a certain vehicle model by used the digital dummy model [5]. Hu Zhiyuan et al. studied the damage of rear passengers under frontal collision [6]. Yan Linbo used the method scaling to get a dummy model that fit the size of the Chinese human body on the basis of the 50th percentile Hybrid III male dummy model, and based on this model to analyze the damage of the occupants [7]. At present, Hybrid III dummy is the most widely used model at home and abroad, which can accurately reflect the biomechanical response of real human body during collision in terms of geometric structure and physical characteristics. However, the disadvantage of this series of dummies is that the hand bionics is not good enough to realize the movement between the knuckles. Most scholars mainly analyze the injury of the people during collision by the dummy hand is in the state of no grasp, without considering the hand grasping state of the dummy. Therefore, there are few studies on the influence of hand grip force on the assessment of injury during collision, and the research results also seldom published. However, roof armrest as an important protection device, the impact of the occupant's grip on the damage assessment should not be ignored. Therefore, according to the robot's hand improved Hybrid III dummy hand to ensure that has the ability to grasp. LS-PREPOST software was used to build a simplified co-driver model of the vehicle, and coupled with the improved dummy model to build a frontal collision model, which was used to study the influence of occupants grasping the roof armrest on the damage analysis, and compare the injury value of the head, neck and chest with the dummy which hand was free during the collision.

The conclusion provides a reference for passive safety protection of passengers in collision.

CREATION OF A FRONTAL COLLISION MODEL

The handrail on the roof of the car is a device to ensure the balance of the occupant, which is rarely used by the drive.

Therefore, in order to speed up the calculation and ensure that the research conclusion is not greatly affected, the simplified model of the passenger cab model was only established in this paper, which includes the window, roof, floor, dashboard, seat belt and handrail. Since the deformation of the passenger cabin during the collision was not considered, just imparts the parts other than the safety belt with rigid materials through the keyword *MAT_RIGID. The safety belt consists of webbing, rewinding, pretensioner, slip ring and buckle, etc. and defines the working characteristics of the reel and slipper ring though the keywords *ELEMENT_SEATBELT_RETRACTO and *ELEMET_SEATBELT_SLIPRING and keywords *MAT_SERBELT define belt material. The passenger cabin model is shown in Figure 1.

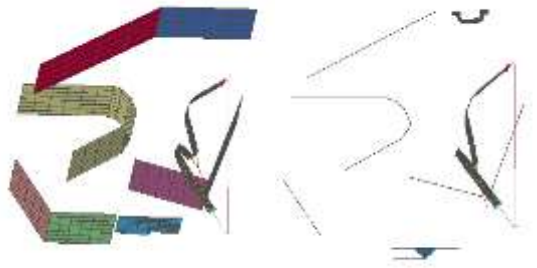


FIGURE 1: THE MODEL OF CO-PILOT

Researchers used the crash test dummy to evaluate vehicle protection for the occupant's effect, which more widely used is Hybrid III dummies. Car crash is a complex process, especially the occupant's movement is an uncertain factor for damage assessment [8]. Therefore, in order to get closer to the real vehicle impact data, the dummy model should not only be close to the real human body in shape and weight, but also in structure and body function. At present, the hand of Hybrid III dummy is designed as a whole part. There is no joint connection at the fingers, which cannot simulate the movement between the fingers of the human body, so as to achieve the function of grasping. Therefore, the hand model was improved on the basis of Hybrid III finite element dummy, which can achieve the ability of hand grasping, so that the occupant can grasp handrails in the collision.

The design of collision dummy model has three principles: anthropomorphism of body structure, similarity of mechanical properties and reproducible. [9] According to the structural characteristics of the robot hand, the improvement was based on the 50 percentile Hybrid III finite element male dummy model that provided by LSTC company. According to the operation manual of the dummy, the height of the dummy is 177 cm and the weight is 86kg. In order to get an accurate date, the hand size date from a man who matched the weight and height. The length, width and circumference of the hand were measured when the person maintained an upright posture with arms freely drooping. Create the model with 3D modeling software and then create the grid by Hyper mesh. As shown in Figure 2. In order to achieve the flexibility of fingers, knuckles need to be connected by rotating hinges.

And the keyword *JOINT_STIFFNESS_GENERALIZED was used to set the friction moment of the hinge to achieve different grip strength of the hand. By changing the angle parameters of the rotating hinge, the movement ability of the finger joints can be realized.

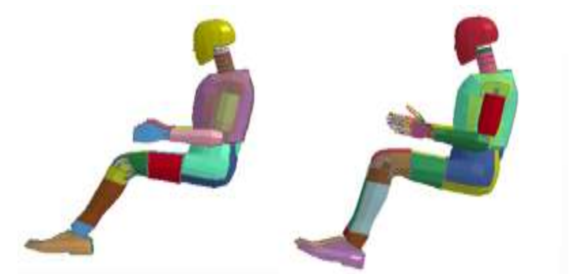
According to literature, the grip strength of the right hand and the left hand is about 38 kg and 35 kg respectively, for young men, the maximum grip strength of the right hand is 56 kg, and that the left hand is 43 kg. Grip strength is related to hand posture and duration of action.

After a period of time, grip strength will significantly decrease [10]. However, the collision can be completed in a very short time. In this process, the grip strength of the passengers to the handrail can be regarded as the instantaneous maximum grip strength. 50 percentile Hybrid Ⅲ dummy can be treated as an adult male, according to Table 1 the grip strength of young men of different ages, it is determined that the maximum grip strength of passengers to the ceiling handrail during the collision is 58.1 kg.

TABLE 1: GRIP STRENGTH OF YOUNG MEN OF DIFFERENT AGES.

Age	Grip Strength (*kg*)		
	Minimum	Standard	Maximum
19	34.5	41.5~48.5	55.5
20	35.7	42.7~49.7	56.7
21	36.7	43.7~50.7	57.7
22	37.7	44.7~51.7	58.7
23	38.1	45.1~52.1	59.1
24	38.5	45.5~52.5	59.5
25	38.7	45.7~52.7	59.7

The 50th percentile Hybrid III male dummy was the original model, and on the premise of not destroy the hand connection relationship of the original dummy and ensuring its integrity, removed the dummy's hands [11]. Since the wrist is connected to the forearm by a rotating hinge, only the lower part of the wrist needs to remove. In order to speed up the calculation without considering the deformation, the hand was set as a rigid body, then the improved hand model was assembled onto the original dummies through the keyword *RIGID_BODIES, as shown in Figure 3.



(a) Original Model. (b) Improved Model.

FIGURE 3: FINITE ELEMENT MODEL HYBRID III MALE SITTING DUMMY.

In order to achieve the simulation requirements, the dummy posture needs to be adjusted before the simulation. Because the preliminary hand model does not belong to the body part of the dummy, that the Angle parameter of its rotation hinge cannot be directly adjusted in the LS-PREPOST software DUMMY interface.

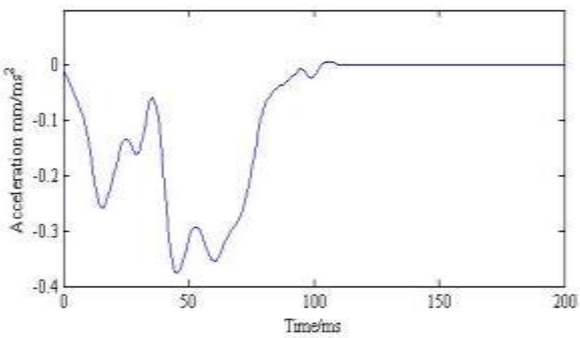
Therefore, the new dummy model should be imported into the OASYS PRIMER software to set the parent-child relationship between the hand and arm, the finger and palm according to the dummy tree file. Then, the improved hand model can realize rotation of wrist and finger by directly inputting angle parameters of rotating hinge [12]. At the same time, the hinge angle parameters of the leg and foot of the dummy were set to make the lower limb contact with the seat and the floor. Finally, the hinge angle of the upper limb and fingers was adjusted to ensure that the hand of the dummy was in the state of grasping the roof armrest. During a collision, the dummy will have greater contact force with the safety belt, ceiling railing, floor, dashboard, and even the windshield. Therefore, it is necessary to define the contact between seat belt and body through keywords *CONTACT_AUTOMATIC_NODES_TO_SURFACE, and the keyword*CONTACT_AUTOMATIC_SURFACE_TO_SURFA E was used to define the contact between the dummy and the seat and armrest, floor, dashboard, windshield, and then set the dynamic and static friction coefficients.

As shown in Figure 4, it is a finite element model which the dummy holds the roof handrail. In order to verify the impact of occupant grasping the roof handrail on the injury assessment results, a comparative simulation model needs to be created. Therefore, follow the previous method to establish the collision model of the dummy in the free sitting state.

FIGURE 4: HUMAN AND VEHICLE COUPLING MODEL

In this paper, the vehicle model was simplified and collision simulation couldn't be realized by adding initial velocity, instead, by adding an acceleration environment during the collision. The acceleration curve was the data collected by the acceleration sensor in the lower segment of B column during the real collision [13], as shown in Figure 5.

FIGURE 5: ACCELERATION CURVE DURING COLLISION.

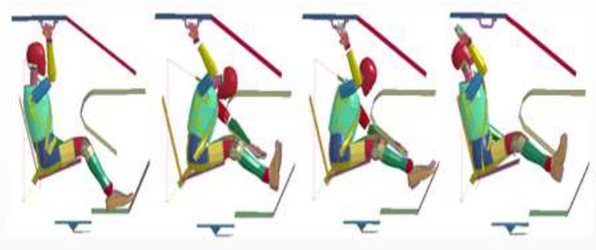


ANALYSIS OF COLLISION SIMULATION RESULTS

The same environmental parameters were set in LS-PREPOST respectively for the model in which the dummy grasped the ceiling handrail and the model in which the dummy hands were in free, and then import into LS-DYNA to solve and obtained the results.

The movement postures of the dummies, as well as the injuries of the head, chest and neck were compared and analyzed under the two working conditions.

The initial posture of the passengers in the car is different, which will lead to different movement states of the passengers in the collision, and the degree of the injury, the collision areas of the body are also different, Figure 6 and Figure 7 are respectively show the motion posture of the dummy under two collision conditions.



0ms 95ms 110ms 190ms

FIGURE 6: STATE RESPONSE OF DUMMY GRASPING ROOF ARMREST DURING COLLISION

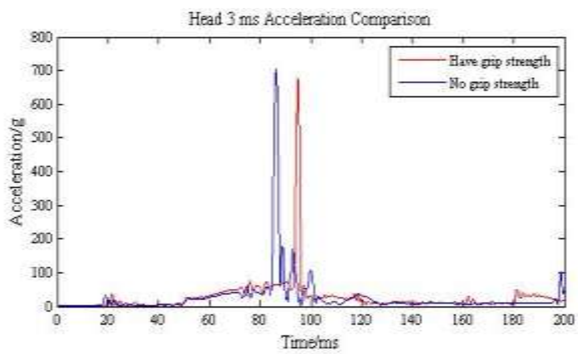
During collision, the vehicle will produce deceleration, and the passengers will continue to move forward due to inertia [14], as shown in figure 6 and figure7, the movement posture of the dummy between 0 ms and 100 ms. By observing the movement posture of the dummy which grasping the ceiling handrail, the head collides with the dashboard at 95 ms, at 110 ms, the impact force caused by deceleration exceeds the maximum grip force of the hand, the dummy's hand is open, that the force on the ceiling handrail disappears, meanwhile, the dummy has started to bounce back, and the chest never touched the dashboard during the crash. As shown in Figure 7, the head of the dummy in the free sitting position collided with the dashboard at 85ms, and the dummy continues to move forward without grip strength, at the same time, the deformation of the neck is larger than the another working condition.

For Hybrid III dummy, the degree of head injury is usually evaluated by HIC and 3 MS resultant acceleration, which calculation formula is [15]:

$$\mathrm{HIC} = (t_2 - t_1)\left\{\frac{1}{t-t}\int_{t_1}^{t_2} a(t)dt\right\}^{2.5} \quad (1)$$

In the formula, t1 to t2 represent the collision time interval with the maximum HIC calculation value. a(t) represents the acceleration of the head's center of mass, which unit is g (Acceleration of gravity). The comparison results of the resultant acceleration of the dummy's as show in Figure 8.

FIGURE 8: THE COMPARISON OF HEAD SYNTHESIS ACCELERATION.



It can be seen from Figure 8 that the trend of the resultant acceleration curve of dummy head under the two working conditions is basically the same, However, the peak resultant acceleration of the dummy's head in the grip state is 6.1% lower than that in the free state. Analysis the reasons: However, there is a delay in the time when the dummy's head touched the dashboard under the action of grip force compared with the dummy's hand is in free. However, from the movement posture of the dummy, the hand force has a great influence on the movement of the trunk, and the head is connected to the torso through the neck, which is very flexible [16], that the grip force of the hand does not directly affect the head motion track and acceleration, thus the head of the dummy with grip force will also have greater acceleration. By calculation, the HIC value of the dummy's head when grasping the armrest was decreased by 30.2% compared with the hand in free. The injury index is shown in Table 2.

TABLE 2: DAMAGE INDEX OF WORKING CONDITIONS

	HIC	C_{3MS}/g
Have grip strength	12 000	662
No grip strength	17 190	705

In basic medical research, some researchers have found that the bending moment generated during the movement can cause damage to human neck. In addition, when S-type movement occurs, its shear force and axial stretching force also cause serious damage to neck tissue [17]. Therefore, the upper neck shear force Fx, tensile force Fz and bending moment My are used as damage indicators for comparative analysis. The result is shown in Figure 9.

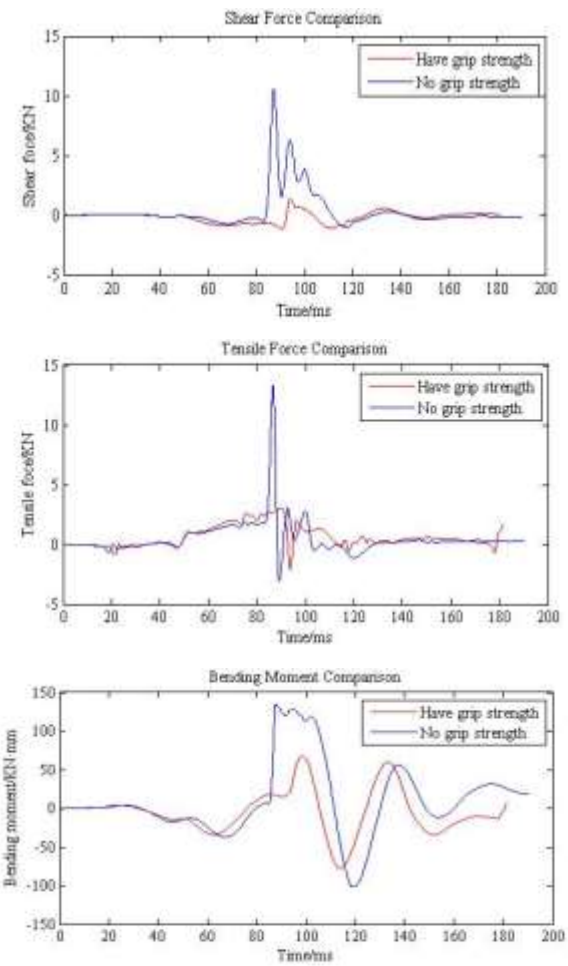


FIGURE 9: COMPARISION OF NECK INJURIES

The results showed that the maximum shear force, maximum tensile force and maximum bending moment of the upper neck of the dummy in the free sitting state are 10.5 KN, 13.1 KN and 136 KN·mm respectively, and the peak values are appeared at the same time as the maximum deformation of the neck during the collision. When grasping the handrail, the maximum shear force, maximum tensile force and maximum bending moment of the upper neck of the dummy are 1.32 KN, 3.02 KN and 77.7 KN·mm, compared with the dummy in the free sitting state, which reduced by 87.4%, 76.9% and 42.9% respectively. In addition, the peak of neck bending moment of the dummy in the free sitting state lasts for a long time, that more damage to the neck of the dummy. It indicates that when the dummy holds the ceiling handrail in the collision, the grip force of the hand can buffer the impact strength generated by deceleration and reduce the forward movement trend of the dummy. When grasping the handrail, the contact time between the head of the dummy and the dashboard is short. The pressure on the neck is small, and the trend of S-shape is obviously reduced, so the value of neck injury is relatively small.

The risk of chest injury to human body is second only to that of head. During the collision, the occupant moves forward due to inertial forces, while being restrained by the safety belt, which will cause sternum and rib injury, internal organ damage, as well as shoulder blade dislocation and fracture [18]. The criteria of chest injury mainly include the criteria of 3 ms and the amount of chest compression. FMVSS208 stipulates that the resultant acceleration of chest should not exceed 60g within 3 ms, Thorax Performance Criteria is the amount of compression of the sternum relative to the spine [19]. Figure 10 shows the comparison of dummy chest injury index values under two working conditions.

Figure 10 shows that the peak value of the chest resultant acceleration and chest compression occurs between 90 ms and 100 ms at both conditions. The maximum resultant acceleration of the thorax is 81.6 g and the compression is 14.7 mm when the dummy is in grip of the ceiling armrest, compared with the maximum resultant acceleration is 166 g and the compression is 17.7 mm of the dummy in the free sitting position, which are reduced by 50.8% and 16.9% respectively.

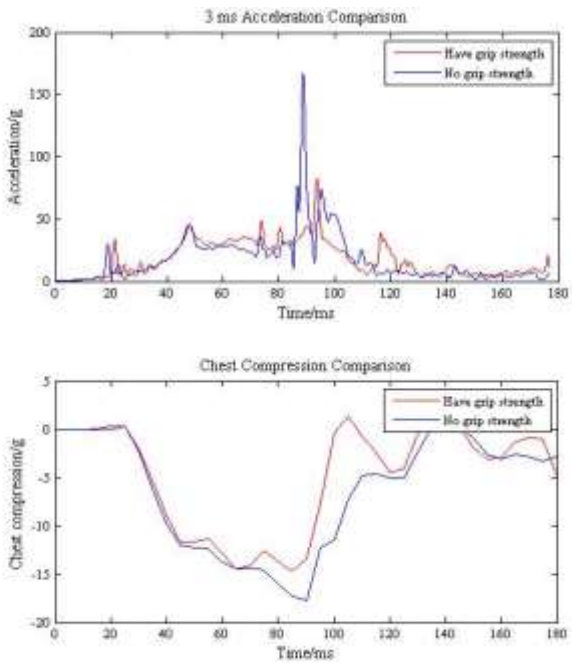


FIGURE 10: COMPARISON OF CHEST INJURIES

This is because the dummy in the free sitting position has no buffer force during the collision, causing a collision between the chest and the dashboard. Therefore, in addition to belt restraint, the contact force with the dashboard will also increase the chest resultant acceleration and the maximum compression [20]. However, during the impact, the thorax of the dummy in the grip state has no contact with the dashboard, so the degree of chest injury is relatively small.

CONCLUSION

In this paper, the simulation is carried out for the two working conditions of the occupant whether or not grasp the ceiling handrail in the frontal collision to compare the dummy's posture and head, neck and chest injuries. The following conclusions are drawn:

The HIC value of the dummy's head with grip force is reduced by 30.2% compared with the dummy in free sitting posture, but the maximum resultant acceleration of the head is only reduced by 6.1%.

When grasping the handrail, the injuries of the neck and chest of the dummy are significantly reduced compared with that of the dummy without grip. The maximum shear force, tensile force and bending moment of the neck are reduced by 87.4%, 76.9% and 42.9% respectively, and the maximum resultant acceleration and compression of the chest are reduced by 50.8% and 16.9%. It is proved that holding the ceiling handrail during collision can affect the movement. posture of the occupants, and can effectively reduce the damage to human body caused by the collision, therefore, in the assessment of personnel injury, the grasping state of the ceiling handrail by the occupant is a factor that cannot be ignored. It can be used to further study the human injury in collision under different acceleration fields.

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