Analysis of driver's seat rigidity in the case of rear-end collisions using a virtual multibody model

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Abstract. The aim of the paper was to analyse the injury potential of the occupant in the case where the backrest of the seat had lower value than normal simulating a broken seat for a rearend collision. The study was conducted using a virtual environment and a multibody model for the occupant. Two test scenarios were taken into account, a rear end collision at 50 km/h with the normal seat and the second where the seat had a lower rigidity value. The results of the simulation show that while the head acceleration values were similar, due to the "whiplash "phenomenon when the seat had a lower rigidity, the injury potential for the occupant was two times higher compared to the normal seat.

1. Introduction

Worldwide, rear-end collisions are the most common type accident between two motor vehicles [1]. The cause of this type of collision is due to the fact that most drivers don't maintain a safety distance between them and the car ahead [2]. This is one reason why automotive manufacturers implemented the adaptive cruise control and the autonomous emergency braking systems as standard in all new vehicles. They can reduce the collision rate by up to 81% [3, 4, and 5]. Rear end collisions have a high injury potential for the occupant's neck and head due to the "whiplash" phenomenon. This type of injury is significant in rear end collisions because it causes long term health problems for the cervical spine, leading to pain and muscle tightness [6]. Over 10 million euros were paid, in Europe, by insurance companies to people who reported symptoms of whiplash after rear-end accidents [7, 8]. This is why this study is conducted in order to obtain valid results regarding the injury potential of the occupant in these types of accients using a virtual model.

The probability of "whiplash" can be predicted using a correlation model between the head-neck and torso rotation angle. A model was obtained by NHTSA(National Highway Traffic Safety Administration) from experimental tests done in a controlled environment and it's presented in figure 1 [9].



Figure 1. Probability of "whiplash" in accordance with the head and torso rotation angle [9]

For a whiplash injury of 100%, the rotation angle is around 84 degrees. This can cause injuries such as muscle tear, vertebra dislocation and fractures. These injuries are not life threating but they can create long term symptoms and limitations such as pain, dizziness, anxiety, muscle stiffness and head rotation turn limit [10].

2. Conducting the simulation

This study was conducted in a virtual environment using the accident reconstruction software called PC-Crash 12.0. The occupant was a multibody mathematical model included in PC-Crash and is presented in figure 2 [11].



Figure 2. Occupant multibody model

The model consists of the different body parts, connected with joints and hinges in order to simulate a real human movement. Also, the seat has 3 components (lower seat, backrest and headrest). In order to simulate a low rigidity backrest, a lower stiffness value was used in the hinge between the lower seat and the backrest. This can be observed in figure 3.

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Figure 3. Seat rigidity values

For this study, a rear-end collision was simulated at a velocity of 50 km/h and the occupant model was positioned in struck vehicle. The vehicle impact position is presented in figure 4.



Figure 4. Vehicle impact position

Vehicle 1 is the struck vehicle (with the occupant) and vehicle 2 is the striking vehicle. The velocity of both vehicles during the collision is presented in figure 5.



Figure 5. Vehicle's velocities during the collision

The striking vehicle velocity drops from 50 km/h to 24 km/h during the impact phase (in the first 50 ms) while the struck vehicle's velocity reaches 29 km/h during that same phase. At 26 km/h we can see that the velocities of the two vehicles are equal.

3. Results obtained from the simulation

The first result is the occupant kinematic during the collision for both situations for normal and low rigidity of the backrest. The kinematic comparison is presented in figure 6.



Figure 6. Occupant kinematic comparison between normal and low rigidy backrest

In can be observed that the case when the backrest has a lower rigidity, the torso has a longer displacement and also the head and neck move at a dangerous angle at 0.14 s during the impact. The maximum angle measured for the head and neck is presented in figure 7.



Figure 7. Maximum angle of the head and neck during the collision

If we observe the maximum angle of neck and head, relative to the torso during the simulation, we obtain a value of 29 degrees in the case of the normal rigidity seat and 62 degrees for the low rigidity case. These value can be correlated with the diagram from figure 1 and a probability of whiplash can be predicted. In the case of the normal seat, a 29 degree angle has a probability of whiplash of 19% while in the other case, 62 degrees corresponds to a probability of whiplash of 63%. The higher probability of whiplash can lead to whiplash related injuries such as neck pain and muscle tightness.

Another result we can focus on is the head acceleration value during the collision. A comparison was achieved for the two cases and presented in figure 8.



Figure 8. Head acceleration comparison

The resultant acceleration is presented for both situation and we can observe that the peak value is 260 m/s^2 . In the low rigidity case of the backrest, two peak values were observed, the first (230 m/s^2 at 0.1 s) represents the initial deceleration of the head, neck and torso in first stage of the collision and the second peak (260 m/s^2 at 0.14 s) was caused by the head hitting the headrest. From this point of view, the maximum peak acceleration of 260 m/s^2 (approx. 26 g's) is not a threat to the occupant due to the fact that studies show the maximum head tolerance limit is 40 g's for more than 50 ms [12].

The final result presented is the contact force between the head and the headrest. This is shown as a comparison graph, similar to the acceleration graph, in figure 9.



Figure 9. Head contact force comparison

In the figure we can see that in the normal seat rigidity, the contact force between the head and the headrest was around 1400 N, while in the second case, the contact force was 850 N. Also, in the low rigidity case we can observe a delay of 50 ms caused by the larger displacement of the backrest. These results show that if the backrest displacement increases, the contact forces are lower because of energy absorption. This phenomenon was observed by Jakobson that developed an anti-whiplash system, installed on Volvo cars called WHIPS (Whiplash Protection System). The system secures the occupant and moves the backrest more than in normal vehicles to absorb a part of the energy [13, 14]. In our case, while the forces are lower, the whiplash probability is higher.

4. Conclusions

The simulation shows that given the case where the backrest has a lower rigidity, the injury potential is higher because of the "whiplash "phenomenon. This is caused by the larger movement of the backrest along with the occupant's body during the collision and generating a high neck angle (of 62 degrees) relative to the torso. Compared to the angle when the seat has normal rigidity (29 degrees), the low rigidity value is double and corresponds to a probability of "whiplash" of 63%.

Head acceleration values for both cases show a similar value of 260 m/s² and do not suggest a threating situation for the occupant. An interesting result is the head contact force with the headrest. In the lower rigidity case is was 40% lower because of the higher movement of the occupant. Because the backrest had a larger displacement, a part of the energy was absorbed and so the contact force had a lower value. Even thou this result would suggest otherwise, the case where the backrest rigidity is lower can present a high risk of injury for the occupant because of the "whiplash" phenomenon and how it can injure the human body.

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