THE ANALYSIS OF THE INFLUENCE OF THE REAR SEAT PASSENGER POSITION ON THE KINEMATICS AND DYNAMIC LOADS ON A TORSO AND LEGS DURING A ROAD ACCIDENT

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Abstract

The analysis carried out by the authors indicates high threat to the rear seat passengers in passenger cars during a road accident. Vehicle designers indicate potential threats for passengers when they take a position in a car which is unexpected by a manufacturer of passive protection systems. Based on that, the tests were prepared in order to consider several different positions of a rear seat passenger. In particular, attention was paid to a threat to passengers when they take a position unexpected by a manufacturer of the passive protection systems in a car. Indicating and justifying a need to adjust the operation of the individual protection means to a passenger anatomy and current passenger position in a car in order to optimize his protection makes an important aim of these tests.

This paper presents the results of the tests performed with a Hybrid III dummy, size M50, placed in three different positions in the back seat of a car. During each test, a series of physical values were measured and the motion of a dummy against the car body and the car interior components were filmed. The effects resulting from a change of a passenger's position, observed on the courses of dynamic loads occurring during an accident, were analysed. Despite of small changes to a passenger's position, their significant influence on the dummy movement during a frontal collision of a car and an obstacle was observed.

Keywords: *road transport, vehicle safety, crash tests, safety of passengers, rear seat*

1. Introduction

There are many factors dependent on a car, affecting the injuries of passengers during a road accident, they include:

- availability of individual protection means in the first seat row and in the following seat rows,
- position of the passengers and space available in the aforementioned seats.

Test results show that in many passenger cars dynamic loads on the rear seat passengers can be much higher than the ones affecting the front seat passengers, so they are subject to a high injury risk [2, 4, 8–10]. A lack of seat belt pretensioners and limiters in the rear seats significantly reduces a possibility of protecting the passengers against injuries. It is proven by the results of the studies [11–13].

Vehicle designers indicate potential threats for passengers when they take a position in a car which is unexpected by a manufacturer of passive protection systems. Such situation is called *Out-of Position* (OoP) [3]. This indicates a need to adjust the operation of individual protection means to information on a passenger's anatomy in order to optimize the protection method. The most common way is to provide properly arranged pressure sensors inside the car seats. The body position on a seat and resulting head, torso and leg distances to the components of a car make an important factor affecting the injuries in a car during a road accident. These factors are conditioned by anthropometric human features and car interior dimensions [1, 7].

Car interior dimensions and first of all a possibility of changing a front seat position significantly affect the position of a rear seat passenger [9]. For example, Fig. 1 shows possible leg positions in a car on the basis of possible positions of the M50 Hybrid III dummy.

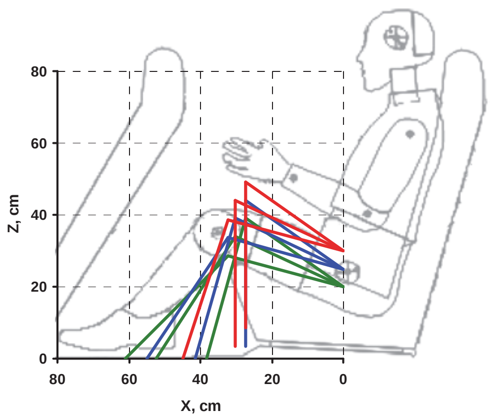

Fig.1. Position of M50 dummy's legs in a back seat [12]

2. Purpose and scope of work

Considering the results [11–13] that indicate high threat risk for the rear seat passengers, the studies have been prepared and carried out involving several different positions of a rear seat passenger occupying the same seat. The tests have been performed and their results allow for evaluating the influence of the rear seat passenger's position on the kinematics of his body (torso and legs) during a road accident. The test result can indicate relations between a taken position by a passenger and the threats resulting from that position. Further on, the results on such analysis will help identify directions of improvement of individual protection means and a need to adjust the operation of these protection means to the information on a passenger's anatomy and his position in a car. Such adjustment process can make use of properly arranged passenger presence detectors, height sensors and passenger pressure sensors in a car.

The effects resulting from a passenger position change, observed on the courses of dynamic loads occurring during an accident, have been analysed. We search for an answer to a following question: do small changes to a passenger position significantly affect the displacements and dynamic loads on the legs and a torso during a frontal collision of a car and an obstacle?

3. Test preparation and measurement conditions

A Hybrid III size M50 dummy was placed in the back seat of a passenger car, including its three different positions in the following tests:

– classic one, where a passenger is resting his back on a rear seat back, with the head in a torso line and legs slightly extended forward, accordingly to a space available in a car, i.e. a distance to a preceding seat (test marked as 2P),
– position as above but feet are withdrawn towards a seat, the head and the neck are visibly inclined towards in relation to the torso (test marked as 3P),
– position with hips moved away from the back but feet withdrawn towards the seat (test marked as 11P).

Initial dummy positions are shown on Fig. 2. Experimental tests included a physical simulation of a frontal collision of a car and a rigid obstacle. Impact velocity amounted to 48 km/h.

Considering the fact that the description of a dummy's position given above before a test is not unequivocal, Fig. 3 and Tab. 1 present additional information and numerical values, characterizing initial position of a dummy.

Fig. 2. Initial dummy position in a rear seat of a car (t = 0 s)

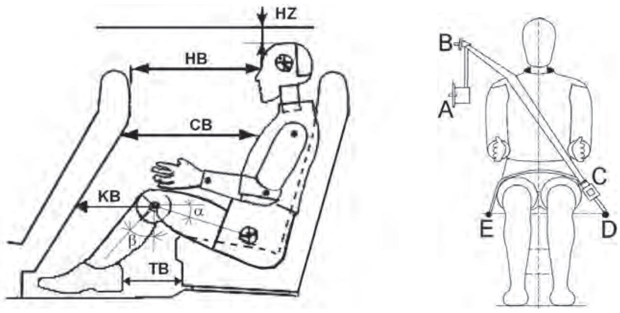

Fig. 3. Dummy's position against cabin interior and safety belt location; BC – shoulder section of a safety belt; CE – hip section, ABCD – belt length from a retractor (A) to a lower fixing point (E). Drawings according to [5]

Tab. 1. Characteristic dimensions of initial dummy's position and the seat belt band against a dummy

Distance in [cm] or angle in [deg]	2P	3P	11P
Distance: arm – seat back edge	3	3	4
Distance: hip – seat back edge	10	10	11
Distance: thigh – seat back edge	9	9	8
HZ	4	5	8
HB	74	72	77
CB	66	67	63
KB – left knee / right knee	27/27	21/21	20/20
TB – left foot /right foot	27/27	13/13	0/0
α – thigh inclination angle (left/right)	20/20	25/25	38/38
β – shank inclination angle (left/right)	35/35	22/22	–10/–10
BC	78	77	84
CE	65	68	80
ABCE	161	163	183

During each test, a series of physical values were measured and the motion of a dummy against the car body and the car interior components were filmed.

4. Test result analysis

The influence of the dummy's position (feet position on the floor and hip position on the seat) on its motion and dynamic loads during a frontal collision of a car and an obstacle is being considered. The results of analysis of 3P and 11P tests are referred to results observed in case of a classic position of a passenger in the back seat (2P). Considerations were started from the analysis of the leg (thigh) motion on the basis of the frame-by-frame analysis of the videos with a 10 ms step. Time $t = 0$ s is the beginning of a contact of the front section of the car and the obstacle. On the both sides of Fig. 4, it was assumed that the initial values of the thigh inclination angle and thigh longitudinal shift are equal zero. So presented courses describe changes (average for the left and the right legs) to thigh position against their condition at the moment of $t = 0$ s, previously described in Tab. 1.

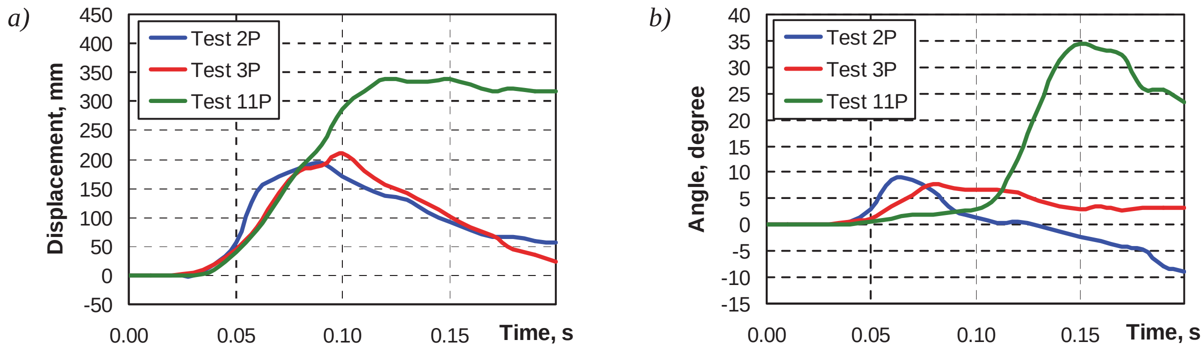

Fig. 4. Thigh longitudinal displacement (a) and thigh inclination angle (b) in 2P, 3P and 11P tests

The change of the thigh inclination angle results from thighs moving on a seat towards the action of inertia and relations between the hip and feet displacement values (compare Fig. 1). Mutual relations between longitudinal hip and feet displacement can be as follows:

– longitudinal hip and feet motion is similar so the thigh inclination angle does not undergo significant changes,
– hip displacement is significantly higher than feet displacement and then the thigh inclination angle increases,
– hip displacement is lower than feet displacement and the thigh inclination angle decreases.

In the 2P test, the feet have a significant freedom in forward motion (including the motion under the front seat), therefore after moving it forward, the thigh inclination angle decreases (negative values on Fig. 4 confirm ”falling” of the knees below their initial position, at the moment of $t = 0$). In the 3P test, the value of the change of the thigh inclination angle values against their initial position is slightly smaller than in 2P. The scope of the value variations for this angle is also smaller in the 3P. While the courses of longitudinal displacement, i.e. thigh gliding on the seat in the time function are similar and the extreme values of that displacement are also similar in those both tests (Fig. 4a). So the initial leg position has a significant influence on the course of thigh inclination angle variations in the both tests in the time function (Fig. 4b).

The courses of inclination angle variations shown on Fig. 4 and the longitudinal thigh displacement in the 2P and 11P are definitely different. In the 11P test, the extreme values of the thigh angle position are three times higher (320% of the angle in 2P), however the longitudinal displacement is almost two times higher (170% of displacement in 2P). Significant longitudinal thigh displacement at high value of their elevation angle results from the process of hips sliding out under the seat belt in the 11P test. Fig. 5 clearly shows the sliding of the dummy’s hips from the seat and pushing out the front seat. The initial position of the dummies was shown earlier on Fig. 2.

The comparison of the thigh motion with the course of the force in thighs and the lap belt is quite interesting. Fig. 6 presents the results of measurements made during the 2P, 3P and 11P tests, namely:

– a course of force in thighs (the lines on the figure show the sum of forces in the left and in the right leg),
– a course of reactions in the lap belt (section CE on Fig. 3, force sensor is placed near point E).

These courses are compared to the car body acceleration (longitudinal component) measured on the ground.

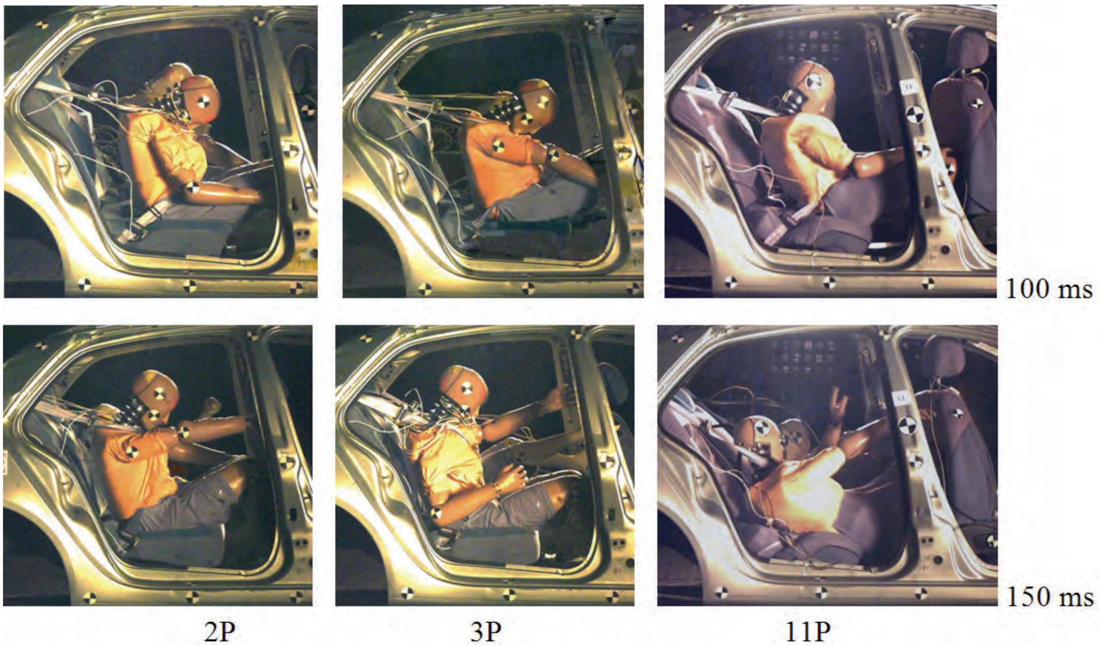

Fig. 5. Dummy location at t = 100 ms and t = 150 ms, in 2P, 3P and 11P tests

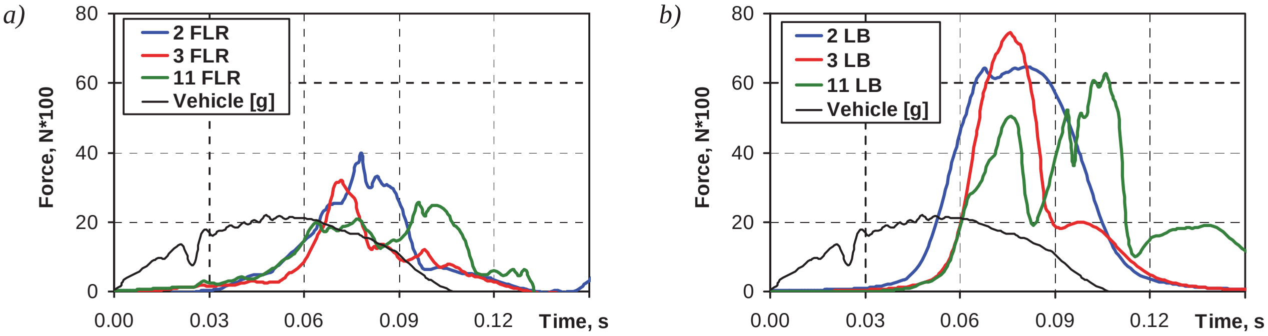

Fig.6. A course of forces in thighs (FLR) and reactions in the lap belt (LB) in the time function

Thighs are stretched with inertia but the values of their loads are small. While the reactions in the lap belt (section CE) are 2–3 times higher. In the 3P test (in about 80 ms), the force stretching the lap belt undergoes sudden decrease, as the knees hit the back of the front seat. That impact is related to a high knee position (compare Fig. 2) in that 3P test position. At the same moment and due to the same reason, the stretching force in thighs is decreased (Fig. 6a). In the 11P test, you can clearly see that the dummy's knees hit the back of the front seat (Fig. 5), as confirmed by the courses in thighs and the lap belt. Significant changes to the lap belt loads in the 11P test also result from the dummy's hips sliding out under a lap belt. As a result, the lap belt moves over a belly in about 80–90 ms (force decrease in the lap belt) and further under the dummy's chest in 100–110 ms (force increase in the belt).

Further comparison of measurement results given on Fig. 7 confirms that the knees hit the back of the preceding seat in the 3P test. That figure specifies the course of force in thighs FLR, force in the lap belt *LB* and the acceleration on the cabin ground *"Vehicle"* and on the back frame of the front seat *PS*. In the period of time of 70-95 ms, strong vibrations of the back of the front seat are visible in the 3P test. While, no such reaction was observed in the 2P test. In the 11P test, the sensor on the seat back was damaged and the course of the legs hitting the seat back was not recorded but it is visible in the frame-by-frame analysis of the videos.

Figure 8a compares courses of resultant torso acceleration, which was calculated from the components measured in three mutually perpendicular directions:

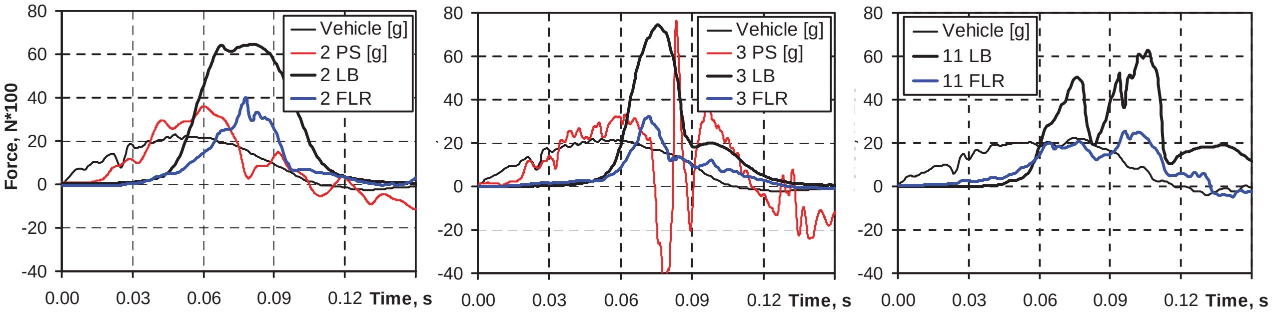

Fig. 7. Association of forces in the belts and legs with the seat back acceleration in 2P, 3P and 11P tests (”Vehicle” – body floor acceleration, PS – front seat back acceleration, LB – force in the lap belt section, FLR – a sum of forces in the left and the right legs)

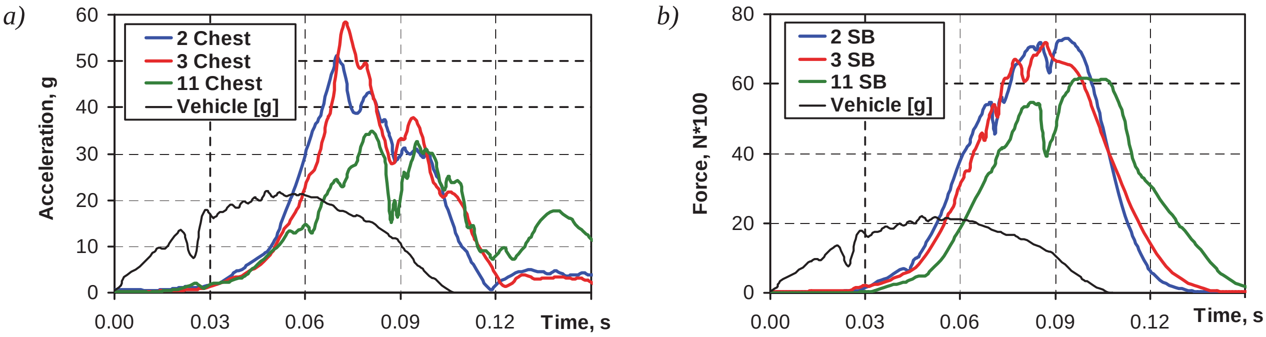

Fig. 8. Courses of torso acceleration (a) and forces (reactions) in the shoulder section of the seat belt (b)

$$a(t) = \sqrt{a_x^2(t) + a_y^2(t) + a_z^2(t)}\,. \tag{1}$$

Courses of torso acceleration in the 2P and 3P tests are similar, so the inertias affecting the torso and forces in the shoulder safety belt are similar. While the resultant torso accelerations in measurements 2P and 11P have clearly different courses. Significant longitudinal displacement of the dummy causes that inertias and reactions in the shoulder section of the seat belt (Fig. 8b) are smaller in 11P than in 2P. The reaction of the shoulder belt in the 11P occurs much later than in the 2P and 3P tests (delay about 10 ms; evaluation and the force level of 400 daN).

The torso movement results most of all from the inertia in the centre of its mass and reaction in the seat belts. Longitudinal shoulder and hip displacements, shown on Fig. 9, describe the torso movement during a collision of a car and an obstacle. A dominating form of that motion is a displacement towards the reaction of inertia. The general character of changes of that shift in the function of the impact time is similar in the 2P and 3P tests, however:

– longitudinal hip displacement in the 3P test is smaller than in the 2P test (by 20%), where the legs are free to move forward;
– longitudinal shoulder displacement in the 3P test is bigger by app. 5% than in the 2P test; so the difficult hip movement (caused by the leg position) resulted in the increased longitudinal displacement of the upper part of the torso, so it also resulted in the increase of the torso inclination angle towards the front seat.

Differences in the dummy’s hip and shoulder displacements in the 2P and 3P tests amount to 3 cm, i.e. about 10% and confirm that small changes in the dummy position in 2P and 3P do not significantly affect the kinematics of its torso.

The dummy displacement turned out to be the biggest in the test 11P. A visible process of hips sliding out under the seat belt is well confirmed by the frame-by-frame analysis of the dummy motion, as shown on Fig. 9, and previously shown on Fig. 5. The extreme values of the longitudinal hip displacement in the test 11P are twice as high are in the test 2P and they exceed 0.4 m. The

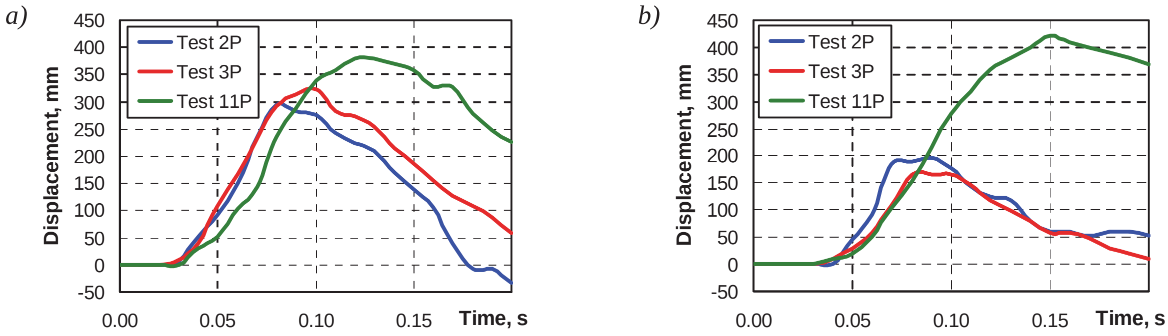

Fig. 9. Longitudinal shoulder (a) and hip displacement (b)

nature of that shift is permanent as the dummy slides out under the seat belts towards the space between the rear seat and the front seat (Fig. 5). The front seat is significantly deformed. It has a significant influence on the shoulder movement and the whole dummy's torso movement. The longitudinal shoulder movement in the test 11P amounts to 0.38 m, so it makes over 130% of the shoulder displacement in the 2P.

Various initial positions of the dummy in the tests 2P, 3P and 11P have also affected the position of the seat belt. The leg position in the tests 3P and 11P affects the visible value of the initial thigh position angle and knee elevation (Tab. 1), and it results in the seat belt position change in the lap section to (section CE, Tab. 1) and elongation of the working seat belt section ABCE from 1.61 m in position 2P to 1.63 m in 3P and until 1.83 m in 11P. The above changes to the dummy's position and the seat belt position also result in:

– the force increase process in thighs is different in both tests, and the increase process in the test 2P is observed in about 43 ms and only in about 55 ms in the 3P test (evaluation at the force level amounting to 500 N);
– in the test 2P, the force in the lap belt starts to increase in about 45 ms, and in the test 3P, that process starts in about 10 ms later;
– in the test 11P, as a consequence of initial knee raise and torso inclination backwards, the lap dace moves to the dummy's stomach and under the chest and it can result in severe injuries of the internal organs.

5. Summary

The experimental tests have confirmed the influence of the leg position angle and leg position on the floor as well as the hip distance from the back of the rear seat on the human body kinematics during a road accident, and most of all on the leg, hip and torso displacement against the seat. For example, courses of the inclination angle variations and longitudinal thigh displacement in the 2P tests (classic dummy position on the seat) and 11P (hips moved away from the back of the rear seat), shown in this paper, are definitely different. In the test 11P, the extreme values of the thigh position angle are over three times higher (320% of the angle in 2P), while the longitudinal displacement is almost two times higher (170% of displacement in 2P).

Other measurement results confirm strong impact of the knees and the back of the preceding seat in the 3P test, and in the 11P test, as a result of initial raise of the knees and moving the hips from the back of the rear seat, in the climax phase of the collision of a car and an obstacle, the dummy moves on the seat under the lap belt. Then the lap section of the seat belt moves from the hips to the stomach and under the chest and it can cause severe injuries of the internal organs.

The tests confirmed that significant factors affecting the injuries of the rear seat passengers in a car during a road accident include a position of their bodies and resulting distance of their heads, torsos and legs from the car components. It indicates a need to adjust the operation of the individual protection means to the information about current position of car passengers in order to improve their protection. These actions can make use of sensors properly arranged inside a car.

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References

[1] Bose, D., Crandall, J. R., Untaroiu, C. D., Maslen, E. H., *Influence of Pre-collision Occupant Parameters on Injury Outcome in a Frontal Collision*, Accident Analysis and Prevention, Vol. 42, 2010.
[2] Campbell, B. J., *The Effectiveness of Rear-Seat Lap-Belts in Crash Injury Reduction*, SAE 870480, 1987.
[3] Dolny, A., Gierczycka-Zbrożek, A., Jaśkiewicz, K., *Zagrożenia związane z działaniem poduszki powietrznej w przypadku niestandardowej pozycji kierowcy samochodu osobowego*, Autobusy, Nr 6, 2010.
[4] Kuppa, S., Saunders, J., Fessahaie, O., *Rear Seat Occupant Protection in Frontal Crashes.* the 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, United States 2005.
[5] NHTSA, *Final Report – Test Number 050506-2*, Vehicle Research and Test Center, East Liberty, USA 2005, (*www.nhtsa.gov*).
[6] Padmanaban, J., Ray, R. M., *Safety Performance of Rear Seat Occupant Restraint Systems*, SAE 922524, 1992.
[7] Rupp, J. D., Miller, C. S., Reed, M. P., Madura, N. H., Ritchie, N. L., Schneider, L. W., *Characterization of Knee Impacts in Frontal Crashes*, the 20th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Lyon, France 2007.
[8] Shimamura, M., Yamazaki, M., Fujita, G., *Method to Evaluate the Effect of Safety Belt Use by Rear Seat Passengers on the Injury Severity of Front Seat Occupants*, Accident Analysis and Prevention, Vol. 37, 2005.
[9] Tavakoli, M., Brelin-Fornari, J., Shetty, V., *Effect of Seat Belts Equipped with Pretensioners on Rear Seat Adult Occupants in High-Severity Rear Impact*, SAE 2008-01-1488, 2008.
[10] Zellmer, H., Lührs, S., Brüggemann, K., *Optimized Restraint Systems for Rear Seat Passengers*, The 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Canada 1996.
[11] Żuchowski, A., Prochowski, L., *Comparative Analysis of Dynamic Loads, Affecting the Children and the Adults, during the Collision of a Passenger Car and an Obstacle*, the 8th International Scientific-Technical Conference on Safety Problems in the Motor Vehicles, pp. 371-378, Kielce, Poland 2012.
[12] Żuchowski, A., Prochowski, L., *The Analysis of Safety of Rear Seat Occupants of a Passenger Car During the Road Accident*, Archives of Automotive Engineering, No. 3, pp. 83-98, 2011.
[13] Żuchowski, A., Prochowski, L., *Analysis of the Influence of the Seat Taken in a Car on the Dynamic Load Affecting People During the Obstacle Impact by the Passenger Car, Automotive safety problems, Vol. 1.*, Wydawnictwo Politechniki Świętokrzyskiej, Kielce, Poland 2012.