

Leon PROCHOWSKI
Andrzej ŻUCHOWSKI

ANALYSIS OF THE INFLUENCE OF PASSENGER POSITION IN A CAR ON A RISK OF INJURIES DURING A CAR ACCIDENT

ANALIZA WPŁYWU POZYCJI CZŁOWIEKA W SAMOCHODZIE NA RYZYKO OBRAŻEŃ W CZASIE WYPADKU DROGOWEGO*

Experimental tests have been prepared and carried out in order to deepen the analysis of the influence of a position of a rear seat passenger in a passenger car on a risk of injuries during a road accident. This risk is considered and calculated in the aspect of a car passenger position that slightly deviates from the one planned by manufacturers of individual protection devices. Attention was focused on the analysis of measurable effects of the position modification in the area of torso and head movement and neck deformation. The experimental tests included a physical simulation of a frontal collision of a car and a rigid obstacle. They showed that relatively small changes to the initial dummy position could be a reason of significant differences in the movement trajectory and dummy position at the final stage of the crash test. These differences are described in details. The analysis also included the criteria index values that refer to the head, neck and chest injuries. Index calculation results confirm the influence of a small change to the leg and torso position on the index values, thus on the probability of injuries of the rear seat passengers in a passenger car.

Keywords: road transport, crash tests, safety of passengers.

Przygotowano i przeprowadzono badania eksperymentalne, które mają na celu pogłębienie analizy wpływu pozycji osoby siedzącej na tylnym siedzeniu w samochodzie osobowym na ryzyko jej obrażeń w czasie wypadku drogowego. Ryzyko to jest rozważane i obliczone w aspekcie zajmowania przez człowieka w samochodzie pozycji nieznacznie odbiegającej od zaplanowanej przez producentów urządzeń ochrony indywidualnej. Uwagę skupiono na analizie wymiernych skutków zmiany tej pozycji w obszarze ruchu torsu i głowy oraz odkształcenia szyi. Badania eksperymentalne były symulacją fizyczną czołowego uderzenia samochodu w sztywną przeszkodę. Pokazały one, że stosunkowo niewielkie różnice w początkowej pozycji manekina mogą być przyczyną znacznych różnic w trajektorii ruchu oraz położeniu manekina w kulminacyjnej fazie testu zderzeniowego. Różnice te zostały szczegółowo opisane. Analizie poddano także wartości wskaźników kryterialnych, które dotyczą powstawania obrażeń głowy, szyi i klatki piersiowej. Wyniki obliczeń wskaźników potwierdzają wpływ już niewielkiej zmiany położenia nóg i torsu na ich wartości, a zatem na prawdopodobieństwo powstawania obrażeń u osób jadących na tylnych siedzeniach samochodu osobowego.

Słowa kluczowe: transport drogowy, testy zderzeniowe, bezpieczeństwo pasażerów.

1. Introduction

The objective of improvement of the means of transport is to increase people mobility, including a possibility of driving at higher and higher speeds. At the same time, threats related to the use of that means become more and more serious [6, 11, 13, 16, 18, 20]:

- constant excessive number of accidents and victims;
- the majority of people occupy a position in a car that is unexpected by manufacturers of passive safety equipment;
- dynamic loads of passengers in the rear rows of seats are often several times higher than in case of the front seat passengers.

These problems line out the area of considerations in this paper and refer to the issue of safe vehicle usage, presenting the example with passenger cars. Using a vehicle should be combined with awareness of effects of improper use of passive safety devices (safety belt, seat). For example, a passenger position, unexpected by a manufacturer of safety devices, i.e. the so-called *Out-of Position* (OoP), can create possible threats for passengers. Studying these threats and reasons of their occurrence when using a car make a subject of studies and analyses in this paper. The analysis of reasons of threats related to a position occupied in a car has a significant social aspect, including a scope of driver training.

The papers [4, 18, 19, 20] present a comparative evaluation of loads that affect the passengers in the front and rear seats of a car during a head-on collision of a car and an obstacle. It was found there that dynamic loads of people in the rear seats are often several times higher than the front seat passengers. These differences result from occupied positions, available space and efficiency of applied individual protection devices.

In contemporary passenger cars, rear seat passenger protection equipment might not be able to provide the same safety level as for the front seat passengers. Relations in injuries of adult passengers in the first and the second row of seats become reverse to the ones that were characteristic for cars 20–30 years ago [5, 7, 12, 16].

The authors of this paper [15] have carried out the analysis of the influence of a rear seat passenger's position on the motion trajectory and dynamic loads during a head-on collision of a car and an obstacle. Tests were performed and measurements were made in order to define a course and dynamic load values, resulting from the action of the force of inertia and reaction of the seat belts.

A dummy was placed in the rear seat of a passenger car. It had a different initial position in the following tests. Detailed specification of dimensions and distances characterizing these positions are given in [15]. The effects of the initial position modification, observed on

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie www.ein.org.pl

the trajectory of the torso and head movement and on the dynamic loads, occurring during a head-on collision of a car and an obstacle, were analysed.

The objective of this paper is to deepen the analysis of the effect of the rear seat passenger's position in a passenger car on a proper operation of the protection equipment. That operation is evaluated on the basis of analysis of the passenger displacement and a possibility of injuries during a road accident. The attention was focused on the torso and head movement analysis. Relation between the torso and the head displacement strongly affects the spine deformation on the neck section. The authors want to answer the question whether small changes in the initial leg and hip positions against the seat have a significant and measurable influence on the operation of protective devices, including the influence on the condition of dynamic loads af-

fecting the passenger's torso, neck and head during a frontal collision of a car and an obstacle.

2. Test preparation and measurement conditions

A Hybrid III size M50 dummy (50-centile male) made the object of the studies. It was placed in the rear seat of a medium class passenger car, including three following positions in the next 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).

The experimental tests were a physical simulation of a frontal collision of a car and a rigid obstacle. The impact speed amounted to 48 km/h. Time $t = 0$ s is a beginning of a car contact with an obstacle.

Figure 1 specifies single video frames that were chosen for a several characteristic moments from a course of a collision of a car and an obstacle. They show relatively small differences in the initial dummy position and at the same time clear differences in the dummy positions at the final stage of the crash test ($t=120$ ms). These differences are described in details further on.

3. Dummy kinetics in the tests 2P, 3P, 11P

The following figures, prepared on the basis of the frame-by-frame analysis of crash test videos, show succeeding dummy positions from the moment of $t = 0$ to 200 ms. Silhouettes were drawn with 20ms interval in two sets:

- time interval 0-100 ms, i.e. 6 following positions in the forward dummy movement;
- time interval 120-200 ms, which includes 5 subsequent positions in the reverse dummy movement from the maximum inclined position to the position occupied at the final stage of the test.

Figures 2 a, b, c allow for general characteristics of the dummy motion in individual tests, including torso displacement in the dummy movement on a seat and the head movement. Figures clearly illustrate the scope of the head movement at two stages of that motion: forward and reverse. Torso and head displacements in the tests 2P and 3P are similar but not the same. However the dummy movement in the test 11P is definitely different than in two previous tests. Figure 2c shows ineffective operation of the seat belt. As a result there was a movement of hips from a seat to the space between the rear seat and the front seat as well as pushing and deformation of the front seat as a result of the leg pressure.



Fig. 1. A diagram of the initial dummy position and its view in the tests 2P (a), 3P (b) and 11P (c) in time $t=0$ ms, 40 ms, 80 ms and 120 ms

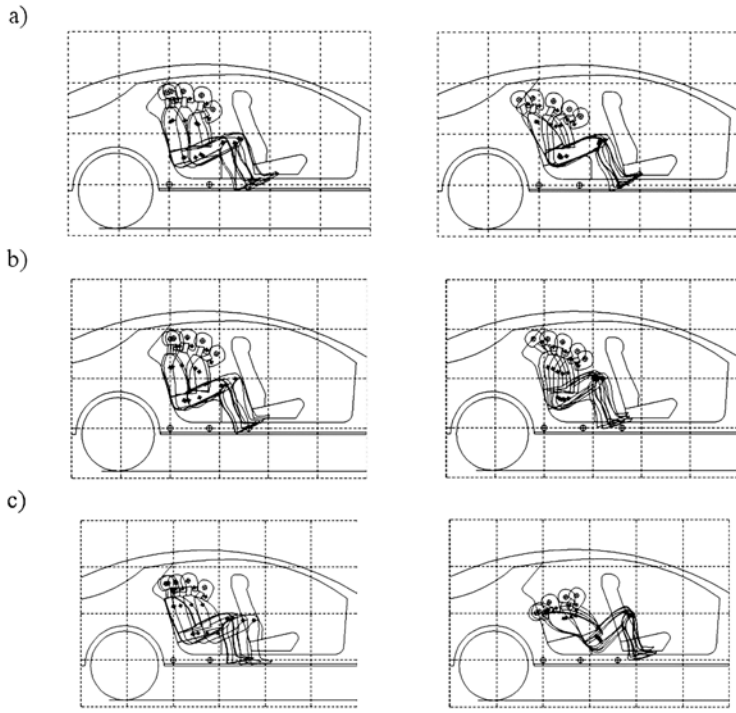


Fig. 2. Dummy displacements against the passenger cabin interior in the tests 2P (a), 3P (b) and 11P (c)

4. Analysis of results in the tests 2P, 3P and 11P

4.1. Analysis of torso movement and affecting force

Analysis of the influence of the dummy position (silhouette) on its kinetics during a road accident was started from identification of leg (high) position change and kinematics. That area of analysis refers to clearly visible differences of the initial state that might affect the behaviour of the dummies. Results of that analysis are presented in this paper [15]. They unequivocally indicate that initial leg position and forces resulting from that position affect the dummy's torso movement. The dummy's torso movement is characterized below by showing the longitudinal displacement of its centre and changes of the torso inclination angle (fig. 3 and table 1). Inclination angle change,

against the initial position for $t = 0$ s, characterizes the torso rotation around the centre of the hip joint. The way of determining the change of the torso position angle is shown on fig. 4. This rotation is most of all a result of action of forces of inertia (caused by a delayed movement of the car body after a car hit an obstacle) and reaction in the seat belt. The dummy's position before the test defines the initial conditions of that movement.

On the basis of figure 3, a mutual relation between the components of the torso movement i.e. its longitudinal displacement and inclination angle was evaluated in the following part of this paper. These relations depend on the initial torso position, as it results from the comparison of courses on figures 3 and 5. Excessive range of the torso movement (shift and rotation) results in a high range of head movement, including the area of risk of hitting the car body components.

The figure 5 shows that changes of the torso inclination angle have a distinctly different course in the analysed tests. Positive values of the inclination angle indicate its forward movement from the position at the moment $t = 0$ s (according to the direction of the pre-impact car speed vector). Negative values indicate that the angle of the torso inclination backwards is higher than its initial value (for $t = 0$ s) in the analysed test. It was possible when the dummy moved on the seat and its hips moved away from the backrest.

The change of the leg position in the test 3P compared to the test 2P affects the torso angle movement, visible on the specification shown on figure 5. The initial leg position assumed in the test 3P resulted in limitation of its longitudinal shift (knees

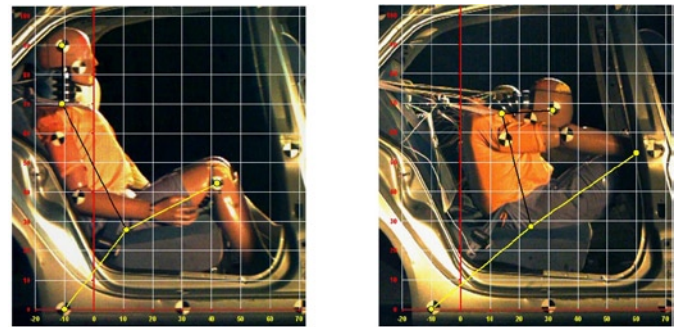


Fig. 4. The way of defining the torso inclination angle using an example from the test 3P (time 0 and 120 ms)

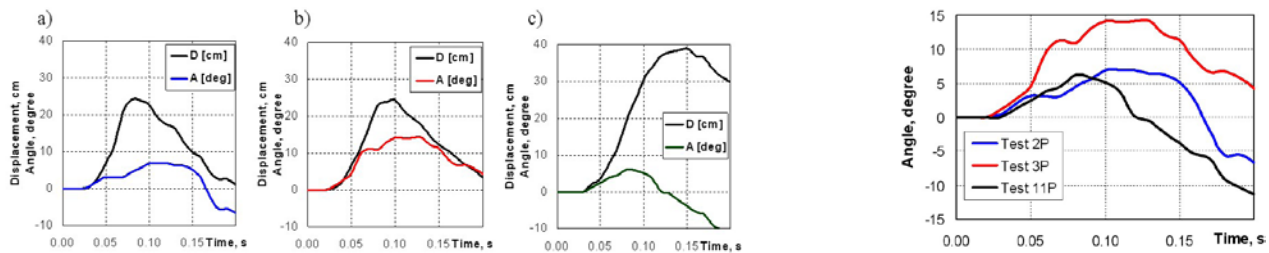


Fig. 3. Longitudinal displacement of the centre of mass of the torso (D) and change of the torso inclination angle (A) in the tests 2P (a), 3P (b) and 11P (c)

Fig. 5. A process of changes in the torso inclination angle in the time function

Table 1. Specification of characteristic values in the torso movement

Value	Test 2P	Test 3P	Test 11P
Maximum longitudinal displacement of the centre of the torso, m	0, 24	0,24	0,39
Change of the torso inclination angle value in the forward movement, degrees	+7	+14	+6
Change of the torso inclination angle value in the reverse movement, degrees	-13	-10	-17

hitting the front seat [15]). It caused the longitudinal hip movement limitation and further action of the force of inertia in the centre of mass of the torso resulted in a significant increase of the torso inclination angle at the final stage of the crash test. The extreme value of the torso inclination angle in 3P is twice higher than in 2P. The angle movement of the torso resulted in

significant acceleration values and force of inertia in the centre of its mass (fig. 6), that are 15 % higher than the ones occurring in the test 2P and result in injury risk increase.

While the initial hip movement away from the rear seat backrest in the test 11P resulted in torso displacement 60 % higher than in 2P and 3P (table 1). The dummy's hips slid down from the seat (fig. 1 and 3c) under the lap belt, which could not operate properly in case of that initial dummy position. Obviously, the dummy motion, occurred in the test 11P, resulted in high dynamic leg and stomach loads, though the extreme torso acceleration values were significantly lower than in the tests 2P and 3P (fig. 6). The process of sliding down the dummy's hips from the seat results in decrease of the acceleration paste in the centre of the torso mass, as the process of braking its longitudinal motion by the seat belts (at the final stage of the impact) becomes weaker, as it can be seen on figure 6 during 50÷60 ms.

The paper [2] identifies the following location of fatal injuries for the rear seat passengers, during frontal collision: head – 25 %, neck – 8 %, chest – 35 % and belly 30 %. The Hybrid III dummy had no sensors in the belly but significant forces in the lap belt, which slid down from the hips on the soft belly in the test 11P, confirm a high injury risk. So it is another important threat signal, which results from an occupied position in towards the passive safety equipment.

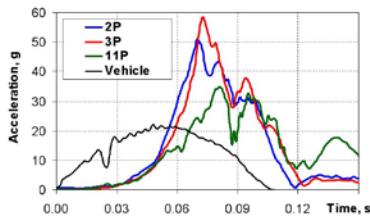


Fig. 6. Resultant acceleration in the centre of the torso

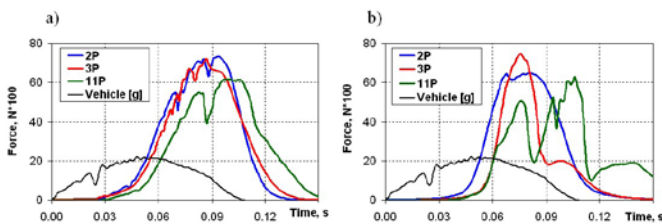


Fig. 7. Comparison of changes in the force, measured on the shoulder seat belt (a) and the lap belt (b)

The courses of resultant torso acceleration in the tests 2P and 3P are similar but the extreme values are about 15 % higher than in the test 3P. It can result from the time accordance ($t = 70\div 80$ ms) of occurrence of the highest torso displacement and rotation in this test (compare fig. 3 and 6). So, despite similar courses of resultant acceleration in the centre of the torso, the change of the leg position angle in the test 3P towards their position in 2P affects the angular motion of the dummy's torso.

The results of the measurement of forces in the shoulder belt (fig. 7a) have similar courses in the tests 2P and 3P. While in the test 11P, the force values in the shoulder belt are clearly smaller than in the previous tests due to the reasons described above. Forces in the lap belt (fig. 7b) have different courses in all three tests. In the test 2P, the lap belt reacts on the dummy clearly earlier than in the tests 3P and 11P. At the final stage of the dummy's movement forward (time $80\div 100$ ms), the force in the lap belt decreases when the knees hit the front seat. On the basis of other observations, it should be also mentioned that the belt displacement on the grommet (between the lap and the shoulder sections) practically do not occur in these tests and it allows for a separate consideration of reaction of the both seat belt sections.

The resultant torso accelerations in the tests 2P and 11P have various courses (fig. 6). However, due to a high scope of longitudinal dummy displacement, forces of inertia and belt reactions in 11P are lower than in 2P. The maximum force values in the lap and the shoulder sections of the seat belt are compared on figure 8.

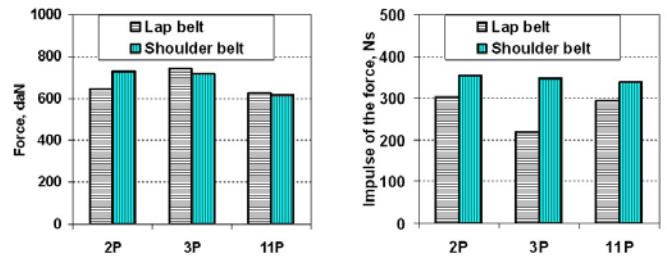


Fig. 8. Maximum values of the force and the impulse of the force acting in the lap and shoulder portions of the seat belt strap (tests 2P, 3P and 11P)

Additionally, the force impulse was calculated for the quantitative evaluation of differences in reaction of the seat belts in individual tests:

$$I = \int_{t=0}^{t_K} F dt \quad (1)$$

where:

F – belt stretching force,

t_K - belt stretching time, $F(t) > 0$.

Figure 8 shows that relations between the maximum force value and the force impulse are different. It confirms the idea of using the force impulse as a supplement of description of the belt load during collision. The force impulse values are clearly smaller for the lap belt than for the shoulder belt, particularly in the test 3P, when the dummy's knees hit the backrest of the front seat, resulting in the belt relief.

4.2. Head movement analysis

Initial differences in the leg and torso positions (classic position 2P and leg position change 3P and hip position change 11P) affected the head movement, and first of all it affected changes of its position towards the torso and the seat backrest. Determination of the head rotation angle changes is based on identification of position of the markers placed on the head in subsequent video frames of the experiment, in a way shown before on figure 4.

On the basis of the frame-by-frame analysis of the test videos, values and a course of changes of longitudinal displacement of the centre of the head mass and its rotation (angular position change) during collision of a car and an obstacle (fig. 9) were determined. That movement is shown towards the initial head position, i.e. for $t = 0$ s. In all tests, the head displacement is very high and amounts to 0,44 m in the test 11P and 0,49 m in the test 2P (table 2). A classic position of the body on the seat (test 2P) leads to the highest head displacements. In the test 11P, a significant scope of the torso movement resulted in limited head displacement.

Obtained results were referred to the paper [3], where many results of the tests on the scope of the human head movement in the crash tests were presented. The tests were performer during 1980-1990. Based on that, an empirical dependence was determined:

$$a = 0,94 \cdot (0,83 \cdot \Delta v + 18) \quad (2)$$

where:

a [cm] – a scope of the head movement towards the car speed vector,

$\Delta v [km/h]$, $a [cm]$ – head velocity decrease value during the test.

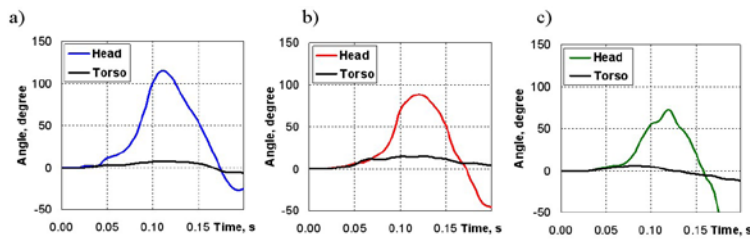


Fig. 9. Longitudinal displacement and rotation angle of the head towards the initial position in the tests 2P (a), 3P (b) and 11P (c)

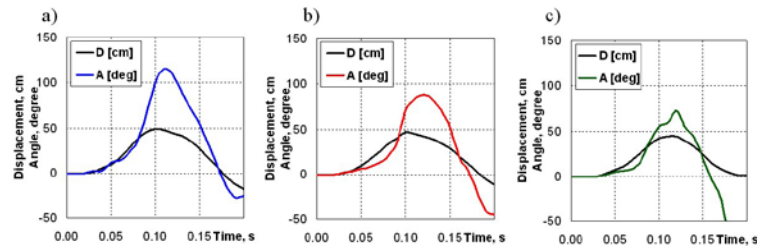


Fig. 10. Comparison of changes in the head and torso position angle changes in the tests 2P (a), 3P (b) and 11P (c)

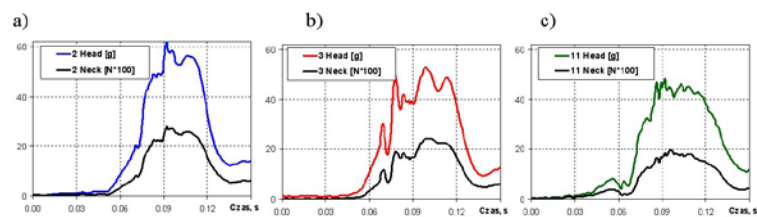


Fig. 11. Resultant head acceleration and resultant force in the neck in the tests 2P (a), 3P (b) and 11P (c)

Table 2. Specification of characteristic values describing the head movement

Value	Test 2P	3P	11P
Maximum longitudinal head displacement, m	0,49	0,47	0,44
Maximum change of the head inclination angle value towards the initial position, degree	115	88	72

On the basis of (2), longitudinal head displacement was calculated for the conditions of performed tests and the following value was obtained $a = 0,54$ m. So the distance defined on the basis of experimental tests carried out during 1980–1990 [3] is higher by 10–17 % than the one currently observed in the tests of that type (table 2). It can be interpreted as a good proof of progress in operation of the individual protection equipment.

Conclusions from the comparison of results shown on figure 10, where courses of the head and torso position angle changes in the time function in subsequent tests are presented, are interesting. In the tests 2P and 3P, where the torso movement is strongly (but properly) limited (table 1) by effective influence of the belt reaction forces, the extreme values of the angular head and torso movement occur at the same stage of the car and obstacle collision process, i.e. 115–125 ms (fig. 10 a, b). While in the test 11P, where the belt did not operate properly, the extreme values of the torso rotation angle occurred already in 80–90 ms (fig. 10 c), and at the later stage of the impact the torso slides on the seat. During that slide the hips slide out from under the belt to the space between the rear seat and the front seat. The torso

inclination angle decreases but the head rotation angle value continues to increase during the time up to 120 ms.

4.3. Relation between courses of dynamic loads affecting the head and the neck (force in the neck)

Performed measurements confirmed that relatively small changes in the passenger position and location towards the individual protection equipment in a car have a significant influence on the risk of head and neck injuries during a road accident. These injuries occur as a result of forces of inertia caused by the presence of high head acceleration values. Courses of resultant head acceleration $a_G(t)$, compared on figure 11, show that position change results in:

- delay of the beginning of the intense acceleration value increase process (evaluated at the level of 10 g) by about 10 ms; the beginning of the intense increase of the value $a_G(t)$ in the tests P2 and P3 was observed in time of about 60 ms and 70÷72 ms in the test 11P;
- decrease of extreme head acceleration values by about 6-10 % in the test 11P towards the values measured in the tests 2P and 3P;
- delay of the beginning of the intense neck dynamic load increase process by about 5 ms (evaluated value obtaining time at the level of 30 % of the extreme values); that beginning was estimated for 68÷70 ms in the tests 2P and 3P and 72÷75 ms in the test 11P;
- decrease of the extreme values of the resultant force in the neck by 20÷24 % in the test 11P towards 2P and 3P.

5. Analysis of biomechanical index values

Calculations of biomechanical index values make the final element of the evaluation of the results of the passenger position change towards the seat and the seat belts. Three indexes were used HIC , N_{ij} , $CAcc$. Head Injury Criterion (HIC) calculated on the basis of head acceleration, make the basis for the injury risk evaluation. Acceleration of the centre of the head, measured in three mutually perpendicular directions, was used in the following way:

$$HIC = \max \left[\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a_G(t) dt \right]^{2,5} \cdot (t_2 - t_1) \quad (3)$$

where:

$a_G(t)$ – resultant acceleration of the centre of the head in g;

$\Delta t = t_2 - t_1$ - time interval in seconds when the highest head acceleration values occur.

Calculated values, shown on figure 12, do not exceed the criterion $HIC=1000$ (and it means 50 % injury risk at AIS scale at the level of AIS2+ or 24 % at the level AIS3+ [17]). The highest value occurred in the test 2P. The highest head load level in this test is confirmed by results shown on figures 10 and 11 and in the table 2. They result from a free head movement towards the body in a classic passenger position on a seat in a car. In the remaining two tests, where a small torso movement away from the backrest was applied and its higher angle of deviation backward from the vertical position than in 2P, a free head movement was limited and it resulted in a lower dynamic load.

The head movement towards the body can result in the neck spine injuries, and their type depends on the direction of the head movement under the influence of the force of inertia and the pressure of the torso.

The risk injury is evaluated by using the index N_{ij} , and its value is calculated as follows [14]:

$$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_{OCy}}{M_{yc}} \quad (4)$$

where:

F_z, M_{OCy} – axial force (F_T, F_C – tension, compression) and corrected moment of bending the neck towards the axis Oy (M_E, M_F – flexion, extension),
 F_{zc}, M_{yc} – critical values of forces F_T and F_C and moments M_E and M_F .

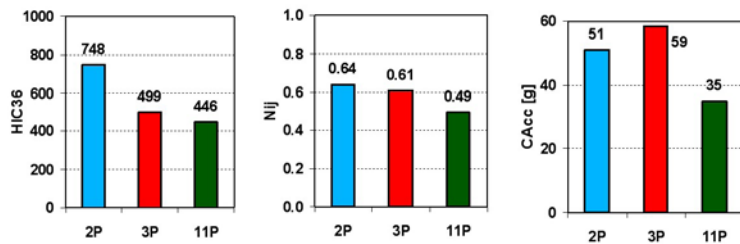


Fig. 12. Biomechanical index values, calculated on the basis of the results of measurements for three positions of the rear seat passengers in a passenger car

The criterion index value N_{ij} should be lower than 1. The value $N_{ij}=1$ means 30 % risk of occurrence of medium injuries at the level of AIS2+ or 18 % risk of very severe injuries AIS4+ [1]. In performed tests, the index values are high and highest ones in 2P and 3P. The definitely lower value of the neck injury index in the test 11P (lower by 20 %) is conditioned by excessive torso movement and it allowed for reduction of dynamic loads of the head and the neck, but it occurred at the expense of excessive dynamic loads of the passenger's legs, belly and the lower section of the spine.

During chest injury risk evaluation, the values of its maximum acceleration $CAcc$, were used that occurred in time of at least 3 ms. The value $CAcc = 60$ g means 20 % risk of very severe injuries AIS4+ [9]. The risk of chest injuries is additionally evaluated on the basis of the maximum value of the force of stretching the shoulder belt during collision. Considering that they amounted to the level of 600-700 daN (compare Fig. 7), so according to the paper [8], a risk of severe injuries (AIS3+) for people at the age of 30 years amounts

to 5-10 %, but for people at the age of over 50 years it is as high as 60-100 %.

Calculated values of biomechanical indexes confirm that there is a high risk of injuries for passengers. The influence of the position change on the level of that risk is visible but not unequivocal. It indicates that passive safety equipment is incompatible with passenger position change in cars. Despite the fact that the latest model of Hybrid III dummy model was used for the tests, it does not allow for detection of all threats occurring due to a limited efficiency of operation of individual protection equipment.

6. Summary

Test and measurement results were presented where three different initial dummy's positions on a rear seat of a passenger car were applied. The results of the change to the initial position towards the individual protection equipment caused by the changes to the torso and the head movement trajectory and dynamic load values, occurring during frontal collision of a car and an obstacle, were analysed. The subsequent figures show general characteristics of the dummy movement in individual tests, including torso displacement in its movement on a seat and the head movement. Already small changes to the initial torso position towards the classic position (test 2P) result in its displacement at the final stage of the accident by over 80 % (compare test 11P). In all tests the head displacement is very high and amounts to 0,44 m in the test 11P and up to 0,49 m in the test 2P. A classic body position on a seat (compare the test 2P) leads to the highest head displacements that are by over 10% higher than in 11P. In the last test a significant range of the torso movement resulted in limitation of the angular head movement.

It should be strongly highlighted that relatively small changes to a passenger position and location towards the individual protection equipment in a car have a serious influence on a risk of injuries during a road accident. That risk was evaluated for each position change. Calculated values of the probability of the head, neck and chest injuries are high and directly indicate that there is a need to adjust protection devices to changing positions of the rear seat passengers, including changes to their position while driving.

Acknowledgement: The research work was done as part of N N509 559640 Project, funded by the National Science Centre, Poland

References

- Adam T, Untaroiu CD. Identification of Occupant Posture Using a Bayesian Classification Methodology to Reduce the Risk of Injury in a Collision. *Transportation Research*, 2011; Part C 19: 1078–1094.
- Aduma S, Oota K, Nagumo H, Okabe T. Development of New Airbag System for Rear-Seat Occupants. The 21th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Stuttgart, Germany, 2009.
- Araszewski M, Roenitz E, Toor A. Maximum Head Displacement of Vehicle Occupants Restrained by Lap and Torso Seat Belts in Frontal Impacts. *SAE Technical Paper Series 1999*; 1999-01-0443.
- Bidez MW, Hauschild HW, Syson SR, Mergl KM. Lap-Shoulder Belt Performance as a Function of Occupant Size, *SAE Technical Paper Series 2005*; 2005-01-1705.
- Bilston LE, Dud W, Brown J. A matched-cohort analysis of belted front and rear seat occupants in newer and older model vehicles shows that gains in front occupant safety have outpaced gains for rear seat occupants. *Accident Analysis and Prevention* 2010; 42: 1974–1977.
- Bose D, Crandall JR, Untaroiu CD, Maslen EH. Influence of pre-collision occupant parameters on injury outcome in a frontal collision. *Accident Analysis and Prevention* 2010; 42: 1398–1407.

7. Evans L, Frick MC. Seating Position in Cars and Fatality Risk. USA, American Journal of Public Health 1988; Vol. 78, No. 11: 1456-1458.
8. Foret-Bruno J-Y, Trosseille X, Lecoz Y, Bendjellal F, Steyer C, Phalempin T, Villeforceix D, Dandres P and Got C. Thoracic Injury Risk in Frontal Car Crashes with Occupant Restrained with Belt Load Limiter. SAE Technical Paper 983166, 1998.
9. Hackney JR, Kahane CJ. The New Car Assessment Program: Five Star Rating System and Vehicle Safety Performance Characteristics. SAE Technical Paper 950888, 1995.
10. Jurecki R, Stańczyk TL. The Test Methods and the Reaction Time of Drivers. *Eksploracja i Niezawodność – Maintenance and Reliability* 2011; 3: 84-91.
11. Kisilowski J, Zalewski J. Chosen Problems of Road Accidents Analyses in Poland in the Period Between 1995 and 2004. *Eksploracja i Niezawodność – Maintenance and Reliability* 2008; 1: 37-43.
12. Martin JL, Lardy A, Compigne S. Specificities of Rear Occupant Protection: Analysis of French Accident Data. IRCOBI Conference, pp. 315-318, Hanover, Germany 2010.
13. Merkisz J, Tarkowski S. Selected Aspects of Using Deck Recorders in Automotive Vehicles. *Eksploracja i Niezawodność – Maintenance and Reliability* 2011; 2: 50-58.
14. Pike JA. Neck Injury Biomechanics, SAE International PT-141, 2009.
15. Prochowski L, Żuchowski A. 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. *Journal of KONES*, 2013; Vol.20. 335-342
16. Smith KM, Cummings P. Passenger seating position and the risk of passenger death in traffic crashes: a matched cohort study. *Injury Prevention* 2006; 12: 83–86.
17. Wicher J. Bezpieczeństwo samochodów i ruchu drogowego. WKŁ, Warszawa 2012.
18. 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*, Wydawnictwo Politechniki Świętokrzyskiej 2012; Vol.1: 113-126.
19. Żuchowski A, Prochowski L. The Analysis of Safety of Rear Seat Occupants of a Passenger Car during the Road Accident. *The Archives of Automotive Engineering*, Warsaw 2011; 3: 83-98.
20. Żuchowski A. Risk of Injury for the Front and Rear Seat Passengers of the Passenger Cars in Frontal Impact. *Journal of KONES Powertrain and Transport* 2012; Vol.19, No.3: 507-518.

Leon PROCHOWSKI

Andrzej ŻUCHOWSKI

Institute of Motor Vehicles and Transportation

Faculty of Mechanical Engineering

Military University of Technology

ul. Gen. S. Kaliskiego 2, 00-908 Warsaw 49, Poland

E-mails: lprochowski@wat.edu.pl, e-mail: azuchowski@wat.edu.pl
