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IMPACT OF USING PASSIVE SAFETY SYSTEMS ON CHILD TRAUMA DURING A FRONTAL COLLISION

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Abstract: *The aim of this paper is the assessment of child's position during a frontal crash. As part of this research, numerical tests were performed using Madymo software, where five different positions taken by a child during car travel were assessed. The research has shown that the child's position during a frontal collision has an impact on the injury criteria. However, passive safety systems are able to effectively protect young passengers from serious injuries. The study showed that positions taken while sleeping, playing with toys, or operating electronic devices are at a slightly higher risk of head, chest and neck injuries compared to the correct model position. A greater likelihood of injury was noted for two positions where the seat belt did not work optimally (there were noted a slipping of the dummy from under the hip belt or slipping of the shoulder belt, which led to increased activity of the belt around the child's abdomen). Tests indicate that the child may behave naturally while driving, but limit positions should be avoided, which may contribute to abnormal operation of passive safety systems.*

Keywords: Frontal collision, Passive safety systems, Child trauma, Car accident, Madymo.

1. Introduction

Currently, a car is an inseparable element of every adult human - in Poland it is assumed that every second Pole has his own passenger car. Statistical data in Poland clearly indicate that around 5500 deaths on Polish roads every year, 42 % as a result of frontal or side collisions, in which children participate in over 45 %. As a result of many real and model tests (Joszko et al., 2016, Jamroziak et al., 2020), it was established how to properly fasten the seat belt to prevent additional and life-threatening injuries, and how to properly select a seat for the child's age and weight. However, it is well known that children in motor vehicles do not always sit according to the crash test protocols. In fact, the sitting position often depends on: the child's activity during the ride, the impact of safety systems, the position of the seat belts on the child's body and the general sense of comfort (Brolin et al., 2015). The research conducted in the years 2005 – 2013 examined the attitudes of children when driving a car by analyzing video recordings and photos. It was found that the age of the child, the design of the seat or other safety system, the seat belt geometry (including its tension and location), performing selected activities (e.g. sleeping or using electronic devices require a given body position) have a significant impact on the position adopted, but also the type of road environment (e.g. a winding road causes a slight swing of the child's body in the frontal plane) and a sense of comfort for the child (Andersson et al., 2010, Forman et al., 2011, Jakobsson et al., 2011, Osvalder et al., 2013, Rooij et al., 2013). Therefore, the aim of the study was the impact of the operation of passive safety systems, such as a car seat or seat belt, on the trauma of children while taking different positions at the time of a frontal collision. In 2003, at the 35th NES (Nordic Ergonomics Society) conference in Reykjavik, the positions taken for children and adults in the car were classified. The division has been presented for the frontal and sagittal planes, where the position of the head and torso is determined separately, marking it with the appropriate alphabet letter (Osvalder et al., 2013).

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2. Methods

As part of this research, a numerical model of the car interior was created along with a 10-year-old passenger on the vehicle rear seat in the child safety seat. The model reflects the physical object from the NHTSA experimental study, where the 2007 FORD Five Hundred SEL 4-DOOR car hit a deformable and stationary obstacle at a speed of 59.9 km/h. This collision is qualified as a frontal collision, which means that during the collision there was a lateral offset of the obstacle relative to the vehicle axis - in this case the offset value was 970 mm (i.e. offset to the left by 50 % of the width of the tested car). In experimental studies, the child's mannequin was placed on the rear left seat (behind the driver) in the Graco Highback Turbobooster car seat. The mannequin was tied with standard three-point belt system. Based on the above experimental research in the Madymo software, a numerical model was formulated consisting of the rear part of the interior of a passenger vehicle (floor, rear seat, front seat), a dummy representing a 10-year-old child - P10, car seat matched to the dimensions of a 10-year-old child and seat belts with attachment points. The model developed in the MADYMO software has been verified against the results obtained during the experimental tests. This assessment was made by comparing model kinematics as well as the obtained acceleration values for the characteristic points of the numerical model. The first 300 ms of simulation duration were analyzed. In the comparative assessment of the results of the NHTSA crash test with the results of numerical calculations, the maximum acceleration values for head, torso and pelvis, neck shear force, tensile forces of the shoulder and lap belt and head injury criterion HIC36 and HIC15 (Head Injury Criterion) were used. As part of the verification of the numerical model, it was found that both acceleration waveforms and model kinematics (Tab. 1) show a good correlation between the real object and the numerical model. The observed behavior of the dummy and the analyzed injury parameters are exemplary for a road accident as a result for a frontal collision of two vehicles.

Tab. 1: Summary of video frames from crash test with numerical model simulation.

	0 ms	120 ms	200 ms	240 ms
Physical object				
Numerical model				

For further numerical research, the most frequently taken positions were selected in accordance with the available literature review (Osvalder et al., 2013). Additionally, selected variants were marked according to the classification developed during the Nordic Ergonomics Society conference. During the simulations, the mannequin assumed the position in the following variants (Fig. 1): variant 0 (W0) – AAAA position – correct basic model position, used to carry out model verification, variant 1 (W1) – EBAA position – a position considered to be children as comfortable , option 2 (W2) - BBCB arrangement - sleeping position, option 3 (W3) – CBAA position - position during play and operation of electronic equipment, variant 4 (W4) – BCBB arrangement – position for observing the views outside the window (including twisting) torso), option 5 (W5) – BDDC position - temporary position, occupied while reaching for the element from the floor of the car.

Fig. 1: Selected positions for numerical simulations.

The obtained injury criteria results for each simulation tested were subjected to comparative analysis with the limit values determined for the P10 dummy. The results are presented in Tab. 2.

Tab. 2: Obtained values of traumatic criteria for the simulations tested (limit value (Forman)).

	W0	W1	W2	W3	W4	W5	limit value
HIC_{36}	519.75	615.44	518.5	458.52	326.64	247.29	**1000.00**
HIC_{15}	291.57	363.52	287.76	287.68	148.03	183.39	**700.00**
N_{ij}	0.79	0.89	0.86	0.64	0.55	0.74	**1.00**
C_{Acc} [g]	33.84	43.49	39.03	43.48	45.89	51.31	**60.00**

Comparing the obtained criteria against the limit values it can be seen that no parameter exceeds the limit. For W0, W1 and W2, the highest value was achieved by neck trauma criterion N_{ij}. In the other three variants, the maximum value was achieved by the chest injury criterion C_{Acc}. The highest HIC_{36} value was recorded for the W1, which by 15.5 % exceeds the injury criteria obtained in the basic variant W0. The lowest value was obtained in the last variant, which is 110 % lower than W0. Analyzing the N_{ij} criterion, a higher value than in the W0 sample was obtained in W1 (by 10.2 %) and W2 (by 6.6 %). The lowest value was obtained for the W4 sample, where the parameter was lower by 45.4 % than for W0. The situation is different for the criterion of chest injuries, where each simulation has values higher value than W0 – by 23.6 ± 5.3 % on average. The biggest difference of 34 % was recorded for the W5, while the smallest for W2 – 13.3 %. In the next stage of assessing the trauma of children as a result of a frontal collision, the AIS scale were used. Using the formulas (Penga et al., 2013), probability of injury to various body parts at a given severity level is determined according to the AIS scale. To make an unambiguous assessment of which position generates the highest dummy injury for each simulation, the P_{joint} (Joint Probability of Injury) factor was determined. It expresses the total risk of injury occurring during each simulation. The coefficient was determined from the following formula (Żuchowski et al., 2016):

$$P_{joint} = 1 - (1 - P_1) \cdot (1 - P_2) \cdot (1 - P_3) \tag{1}$$

where: P_1, P_2, P_3 – risk of head injury (P_{head}), for neck (P_{neck}), for the chest (P_{chest}).

The calculated P_{joint} ratio is shown on the bar graph (Fig. 2) for various types of injury - moderate (AIS2+), severe (AIS3+) and very severe (AIS4+).

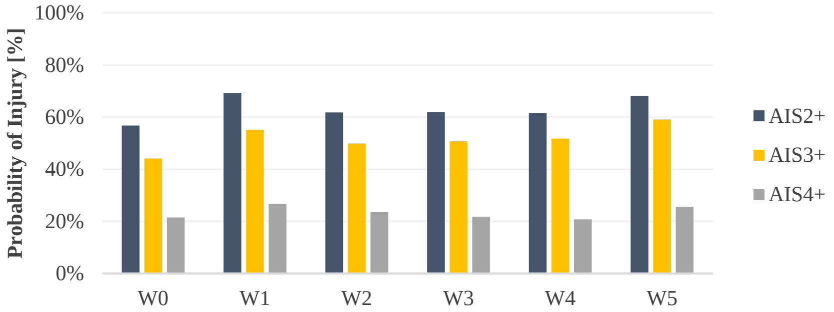

Fig. 2: Risk of total injury to the head, neck and chest in injury simulations AIS2+, AIS3+, AIS4+.

When assessing the risk of total injury for simulated positions during a frontal collision, it can be observed that the most unfavorable variants are the position W1 (position with pelvic forward displacement) and W5 (position when temporarily reaching the floor). It is estimated that in these cases the probability of moderate injuries (AIS2+) is 68 ÷ 69 %, severe (AIS3+) 55 ÷ 59 %, and very severe 26 ÷ 27 %. The smallest expected injuries to a child as a result of a collision were recorded as expected for the basic variant W0, where the risk of medium injuries is 57 %, severe 44 % and very severe 21 %. For variants W2, W3 and W4, virtually identical risk of total injuries was obtained: AIS2 61 ÷ 62 %, AIS3 50 ÷ 52 % and AIS4 21 ÷ 24 %.

3. Conclusions

The carried out research study allowed the assessment of passive safety systems on child trauma. As a result of the research, it was found that in the analyzed cases, seat belts optimally protect children from additional risks associated with a frontal collision. In a situation where they acted in a disturbed manner (slipping from the shoulder or sliding the child out of the waist), a higher probability of injuries was noted. Therefore, this means that the position adopted has an impact on children's trauma - it was observed that the worst results (higher risk of trauma) were noted in variants with disturbed belt operation. The results obtained during the bench tests, where the mannequin most often assumes an upright position (W0) gives the most optimistic picture. The calculated total injury risk is the lowest among the other variants studied. The determined risk of injury of a given case should not be the only criterion taken into account when assessing trauma. The P_{joint} (*Joint Probability of Injury)* factor determined for the tested variants does not take into account the injuries sustained by the abdomen or legs, therefore the results of the dummy kinematics analysis should be taken into account. Consequently, the most dangerous variant turns out to be W1, then W5, W4, W3 and finally W2. The set of results with available literature (Żuchowski et al., 2016), states that the received data are lower than the literature data. For the HIC_{15} and C_{Acc} injury criteria, it is noted that the decrease in value of 27 % for head injury, while the value of the neck injury criteria (Nij) is comparable. The calculated risk of total injuries was also lower in the conducted study - for AIS2 + the values were lower by 36 %, for AIS3+ by 27 % and for AIS4+ by 19 %. The research shows that there is a moderate correlation between the head injury criteria HIC_{36} and the neck injury criterion N_{ij}, where it is noted that with the increase in head injuries there is a tendency to increase in neck injuries. A similar correlation at a moderate level was noted between HIC_{36} and C_{Acc}, but a decreasing tendency was observed here - as the head injuries increased, the chest injuries decreased. In addition, it should be mentioned that the results obtained may be subject to a small error caused by inaccurate presimulation of each model, which was revealed by additional artifacts at the beginning of the simulation.

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