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ASSESSMENT OF THE DANGER ARISING FROM AN IMPACT AGAINST A MOBILE COMPUTER PRESENT IN THE SPACE BETWEEN BUS SEATS DURING A ROAD ACCIDENT

OCENA ZAGROŻENIA WYNIKAJĄCEGO Z UDERZENIA W MOBILNY KOMPUTER W PRZESTRZENI MIĘDZY FOTELAMI AUTOBUSU PODCZAS WYPADKU DROGOWEGO

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Summary

Passenger seats are one of the most important parts of bus equipment. For the sake of passengers' comfort, buses are increasingly often provided with small tables to support a mobile computer, laptop, or tablet in a position convenient for the user of a device of this kind. However, this may be an important source of a hazard during a road accident, especially for children. The objective of this work was to assess the danger that would arise from an impact against a mobile computer and to develop calculation methods that would facilitate the identification of such a hazard as one of the accident effects. The research carried out with this objective in view will help to learn some relations between the seating layout, positioning of the said supports, and anthropometric characteristics of bus passengers. A multibody computer model was built, where a fragment of the passenger compartment of a bus with three seats inclusive of integrated seatbelts was represented. The kinematics of motion of the models of an adult and a child in the space between seats during a frontal impact of the bus against an obstacle was explored. Special attention was paid to the possibility of face injuries resulting from an impact against the surface or front edge of the laptop. The limitations resulting from the possible head movements in the space between the seats as well as the influence of changes in the seat spacing on the velocity and angle of impact of passenger's head against the computer were taken into account.

Keywords: buses, passenger safety, impact against a mobile computer, modelling of passengers' movements

Streszczenie

Fotele pasażerów to jeden z najważniejszych elementów wyposażenia autobusów. W celu zwiększenia wygody osób jadących coraz częściej wyposaża się je w stoliki podtrzymujące mobilny komputer, laptop lub tablet w pozycji dogodnej do jego wykorzystania. To jednak może być istotnym źródłem zagrożenia podczas wypadku drogowego, szczególnie dla dzieci. Celem pracy jest ocena zagrożenia wynikającego z uderzenia w mobilny komputer oraz rozwijanie metod obliczeniowych, które ułatwią identyfikację tego zagrożenia jako skutków wypadku. Prowadzone w tym celu badania ułatwią rozpoznanie niektórych relacji pomiędzy rozmieszczeniem foteli, umieszczeniem podstawek podtrzymujących a cechami antropometrycznymi osób jadących w autobusie. Opracowano wielobryłowy model komputerowy, w którym uwzględniono fragment przestrzeni pasażerskiej autobusu z trzema fotelami wraz ze integrowanymi pasami bezpieczeństwa. Rozważa się kinematykę modeli osoby dorosłej i dziecka w przestrzeni między fotelami podczas czołowego uderzenia autobusu w przeszkodę. Szczególną uwagę zwrócono na możliwość powstania obrażeń twarzy w rezultacie uderzenia w powierzchnię czołową lub przednią krawędź laptopa. Uwzględnia się ograniczenia wynikające z możliwości ruchu głowy w przestrzeni między fotelami, a także wpływ zmiany odległości między nimi na prędkość i kąt uderzenia głową w komputer.

Słowa kluczowe: autobusy, bezpieczeństwo pasażerów, uderzenie w komputer mobilny, modelowanie ruchu pasażerów

1. Introduction

Passenger seats are one of the most important parts of bus equipment. The seats together with seatbelts are basic components of the personal protection system. In buses, two-point seatbelts are becoming popular. Simultaneously, for the sake of passengers' comfort, the seats are increasingly often provided with small tables (supports) to hold a mobile computer, laptop, or tablet in a position convenient for work and entertainment. The passengers (both adults and children) use devices of this type when travelling. This, however, may be a source of a hazard during a road accident [8].

The lap belts will not sufficiently restrain movements of the upper part of passenger's torso and head when the bus hits an obstacle. In such a case, passenger's body will move towards the backrest of the preceding seat and will sometimes hit on it [6]. To reduce the adverse effects of such a collision, proposals were made for the seat backrest to be so designed that, during an accident, it would undergo programmable deformation under pressure exerted by the body of the passenger seated behind and it would thus absorb a part of the impact energy. The presence of a shelf (table) supporting a mobile computer will considerably reduce the possibility of the said deformation and, in addition to this, will pose a hazard to the occupant of the seat behind. An analysis of this issue comes within the area of passive safety of people in public transport.

The issues of passive safety of people in buses are analysed from several points of view. Publications [4, 12] present quite a lot of results of examinations and analyses of bus body stiffness, based on various experiments and computer simulations. These results show that from the point of view of passive safety, the preparation of bus bodies does not provide now adequate passenger protection because of insufficient dissipation of the impact energy by deformation, which results in a possibility of excessive loads to act on passengers' bodies. In other publications [5, 7, 11], the behaviour of human body during a road accident is analysed. The problems related to the passenger's impact against the backrest of the preceding seat are identified and the results of these studies indicate that the current solutions adopted in the construction of seatbelts require further improvement.

An important idea in the works on the safety of bus interior is the compartmentalization (sometimes referred to as "pigeonholing") [3, 9], where endeavours are made to form a number of compartments ("pigeonholes" or "drawers") with walls absorbing the energy of passengers' impacts against vehicle interior components. The main elements of such compartments are seat backrests of considerable height, which constitute the walls, and adequate distance between them. However, the presence of the table and a computer on it in this space (Fig. 1) may be a source of a hazard and injuries.

Fig. 1. Tables attached to bus seat backrests [13]

At present, there is a lack of results of any research works on the influence of the presence of any extra objects in the space around bus passengers on the injuring of the passengers during a road accident. An element of this kind may be a foldable table as shown, with which bus seats are often provided as an additional amenity, and a mobile computer placed on it.

The objective of this work was to assess the danger that would arise from a passenger's impact against a mobile computer during a road accident. Both the course and effects of such an impact were analysed. The influence of distance L_0 between bus seats on the kinematics of motion of a child and an adult in the space between the seats was analysed in detail. Results of this research may help to improve the passive safety of bus passengers.

The work was done with using results of experimental tests for the identification of motion of test dummies in the space between the seats during a bus impact against an obstacle [6, 7, 8]. The said test results were taken as a basis for building a computer model.

2. Model and its properties

A multibody computer model was built, where *inter alia* the following was taken into account:

- process of deformation of the front vehicle part (by applying an acceleration vs time curve as an input);
- compliance of the connection between the seat and the bus floor;
- moments of the resistance to motion in the articulated joints between individual parts of the seats and dummies;
- reaction forces exerted by seatbelt straps on dummy's torso;
- contact forces between individual dummies' parts and the seats and the support with a computer.

The model describes the motion of test dummies H III, size M50 (a 50th percentile adult male dummy) and P10 (a child aged 9-12 years). The geometry of the model is defined by 27 generalized coordinates. To determine the motion of system elements, a system of 54 differential equations was solved. The numerical calculations were carried out by a HYBRID_HYBv105 program specially worked out for this task, operating in the MATLAB environment. An assumption was made that the model movement was planar and its initial velocity was the bus velocity when hitting the obstacle, with its value being v_{0N}.

Fig. 2 shows a general view of the model and the dummy's head as an example of the loads applied, which consist in this case of reactions M_Z and R_Z in the articulated joint, weight $m_1 g$, and forces applied at the points of contact with other parts of the model. The model has been presented in detail in [2]. The primary selection of parameters and characteristics of the model was done on the grounds of measurements of the characteristics of seats, test dummies, seatbelt strap, etc. The experimental tests were carried out at the Automotive Industry Institute (PIMOT). An example of the results of a crash test where a physical model representing a bus segment hit an obstacle with a velocity of v = 30 km/h has been presented in Fig. 3.

Results of the experimental tests (see the example shown in Fig. 3) were used for determining the trajectories of the characteristic points (marks on the dummies); based on this, the imaginary courses of the lines that connect centres of the solids constituting individual dummy components were drawn. Successive positions of these lines (drawn for 0.02 s intervals) have been shown in Fig. 4, based on an analysis of the video record of the crash test. The validation calculations confirmed correct model response to an impact-type input defined by the process of deformation of the bus superstructure during a frontal impact against a rigid obstacle [2, 7].

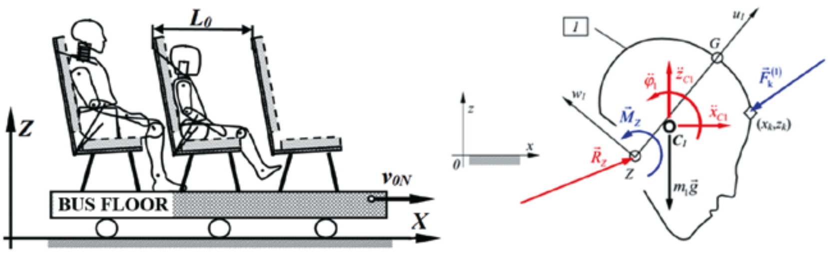

Fig. 2. General view of the model and the head loads (one of the options considered)

Fig. 3. Positions of dummies H III and P10 at successive instants (0-180 ms)

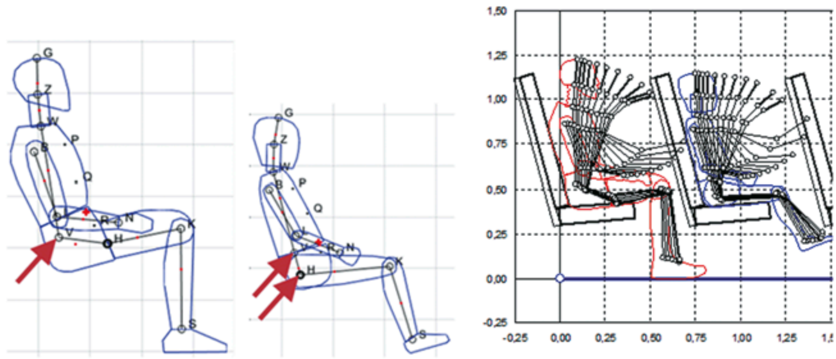

Fig. 4. Characteristic points on the models of the test dummies and their movements during the experiment; the arrows indicate the articulated joints that are important from the torso bending point of view

The computer simulations were carried out with a kinematic input applied as a signal representing the time history of the acceleration of the bus body mass centre during an impact against a rigid barrier with a velocity of v = 50 km/h. Foldable tables to support a mobile computer (laptop) were attached to seat backrests on their rear side. The test dummies were restrained by two-point seatbelts (indicated in Fig. 5 by pink lines). The model was built with taking into account the experience gained from descriptions of the dynamics of a human body, given in [1, 10].

3. Test results

The subject explored was the kinematics of motion of the models of an adult and a child in the space between bus seats during a frontal impact of the bus against an obstacle. The analysis was based on simulation test results. An example animation (where the simulation frames were taken with a step of 0.02 s), showing the motion of models of the test dummies between seats spaced at 0.75 m intervals, with a table to support a mobile computer being attached to the backrest of the preceding seat at a height of 0.72 m from the floor, has been shown in Fig. 5.

The kinematics of the impact of dummy's head against a mobile computer was analysed with considering the influence of distance L_0 between seats on the course and effects of the impact. The nominal distance was 0.75 m, but a number of variants were also examined in succession, where L_0 was reduced in 0.02 m steps to reach a value of 0.65 m. The following parameters were taken into account:

- velocities of dummy's head in directions tangent and normal to the computer plane;
- torso and head bend angles (shown in Fig. 6).

Time histories of these variables were used for determining the values of the following quantities at characteristic instants during the road accident:

- time that elapsed from the instant when the bus hit the obstacle to the instant when the passenger hit on the computer;
- angular position of the impact velocity vector at the instant when passenger's head came into contact with the computer.

These quantities make it possible to determine the energy of impact and the position of passenger's head in relation to the computer at the beginning of contact between them. The most important calculation results regarding the kinematics of a child and an adult have been presented in Figs 7-9 and 10-12, respectively. The calculated time histories of the quantities under interest have been presented for the time interval of 0-0.10 s. This is the period during the road accident under analysis when passengers' movements from the initial position to the instant when the head or torso struck the computer could be seen.

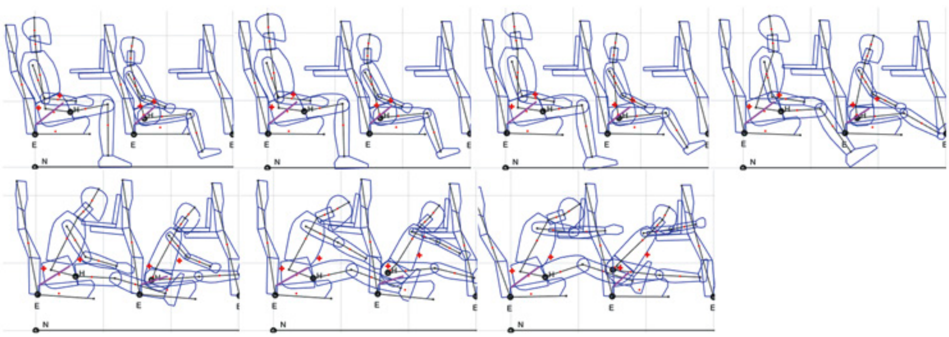

Fig. 5. Computer animation of the motion of bodies of a child and an adult for the time interval of 0-0.12 s (animation step 0.02 s); L_0 = 0.75 m

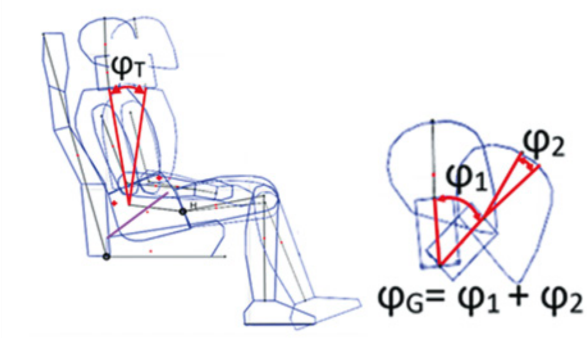

Fig. 6. Torso and head bend angles (φ_T and φ_G, respectively)

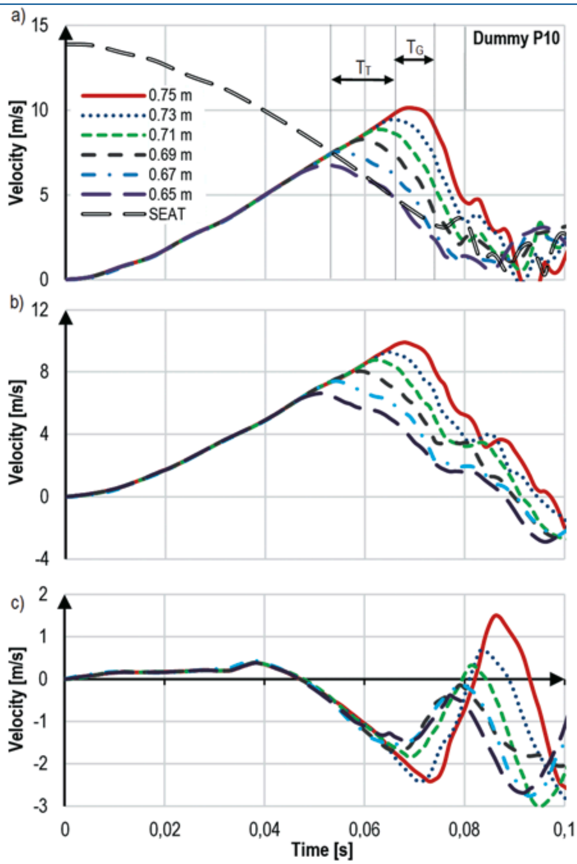

Fig. 7. Dummy P10 head velocity vs time curves for several seat spacing values:

a) resultant velocity;
b) horizontal component of the velocity vector;
c) vertical component of the velocity vector;

T_T – time interval when dummy's torso struck the laptop;
T_G – time interval when dummy's head struck the laptop.

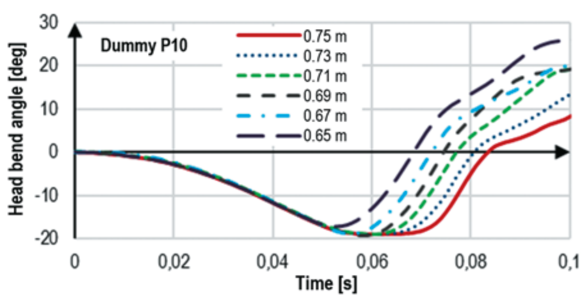

Fig. 8. Dummy P10 head bend angle φ_G vs time curves for several seat spacing values

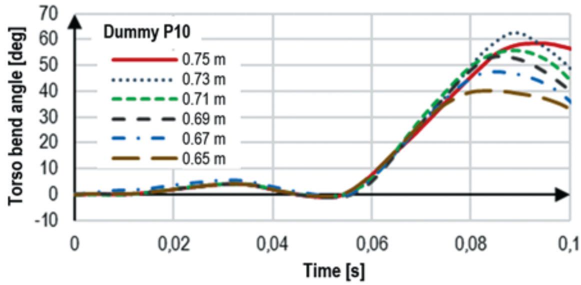

Fig. 9. Dummy P10 torso bend angle φ_T vs time curves for several seat spacing values

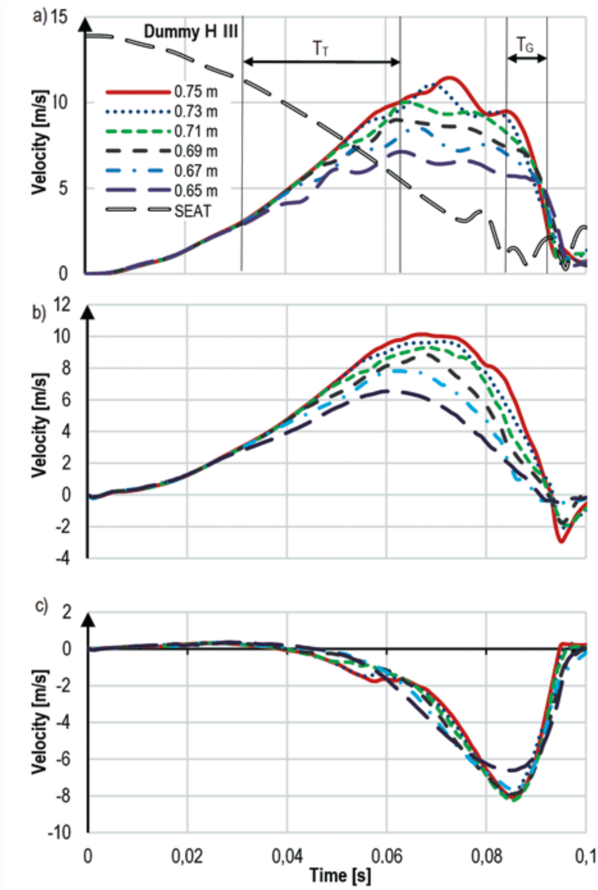

Fig. 10. Dummy H III head velocity vs time curves for several seat spacing values:

a) resultant velocity;
b) horizontal component of the velocity vector;
c) vertical component of the velocity vector;

T_T – time interval when dummy's torso struck the laptop;
T_G – time interval when dummy's head struck the laptop.

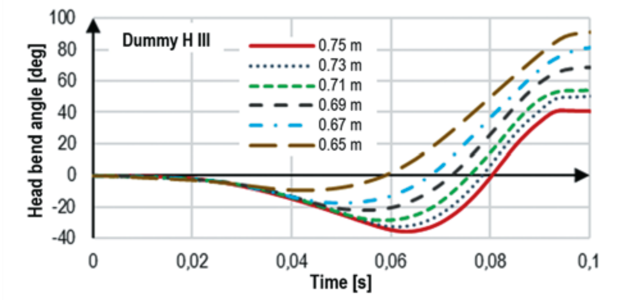

Fig. 11. Dummy H III head bend angle φ_G vs time curves for several seat spacing values

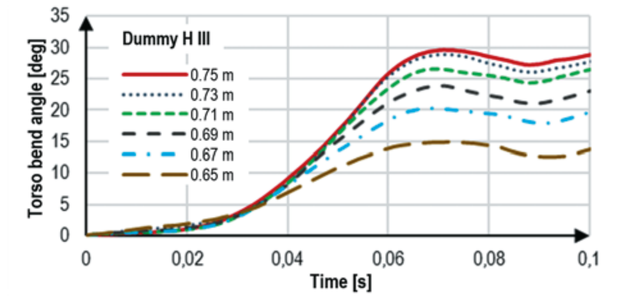

Fig. 12. Dummy H III torso bend angle φ_T vs time curves for several seat spacing values

4. Analysis and discussion of the test results

The calculations carried out make it possible to identify an important hazard that emerges at the instant of an accident and is related to using a mobile computer while travelling. In such a situation, head injuries may be incurred due to a high value of the velocity of impact against the surface or front edge of the laptop.

The histories of child's head velocities (Fig. 7) before the beginning of contact between the head and the computer only slightly depend on the seat spacing. The instant when the torso of dummy P10 hits on the computer takes place at T = 0.056-0.068 s and this time is the shorter the closer the seats are spaced (see Table 1). The calculations revealed (Figs 7b, c) a predominating share of the horizontal component of the child's head velocity vector; this results in a sliding nature of the impact. The time history of the horizontal component of the velocity vector indicates the instant when the impact took place (Fig. 7b) and the effect of this fact, i.e. a sudden change in the value of this component. The vertical component, in turn, shows accelerated downward motion of the head (lowering of the head when the value of this component is negative). In result of this lowering, the head hits on the computer at an instant of 0.068-0.074 s (Table 1) and this downward movement is suddenly stopped. The calculated angle of inclination of the head velocity vector β confirms (Fig. 13) the sliding nature of the impact of this part of child's body against the computer. In this figure, the angle α between the head position and the laptop plane at the instant of impact has also been shown. It was determined as the difference between the values of the head bend angle (Fig. 6) and the angle between the laptop plane and the horizontal plane.

The zone of contact between the dummy and the computer includes also the area of child's neck, which is a particularly alarming result of the calculations because of the susceptibility of this part of a human body to severe injuries. An analysis of this aspect of hitting on the computer will be the subject matter of a separate research work.

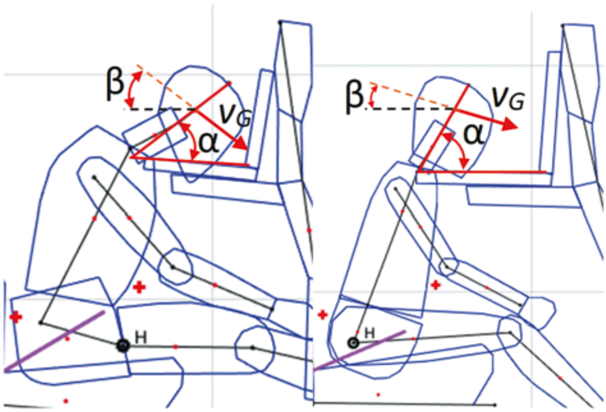

Fig. 13. Head bend angle relative to the mobile computer (α) and angle of inclination (β) of the vector of resultant velocity v_G of the head mass centre of dummy H III (left) and P10 (right) at the instant of hitting on the computer

Before the beginning of contact between child's head and the computer, the angular motion of child's torso and head (Figs 8 and 9) does not depend on distance L0. This motion leads to a growth in the torso bend angle in the direction of the bus velocity vector and to the bending of dummy's head in the opposite direction. The contact phase of the impact process begins at the instant of about 0.062 s at the nominal seat spacing or earlier when this spacing is reduced (Fig. 8). When the torso hits on the computer, the direction of the head motion changes so that the head is bent forwards. This bending is the more intensive the closer the seat spacing is. When the head impact against the computer begins, the process of growth in the torso bend angle is stopped (Fig. 9).

Table 1. Summary of the values of time, velocity, and angular position of the head of dummy P10 at the instant of hitting on the mobile computer

Seat spacing [m]	0.75	0.73	0.71	0.69	0.67	0.65
Instant when dummy's torso hit on the edge of the mobile computer [s]	0.068	0.065	0.065	0.062	0.060	0.056
Instant when dummy's head (face) hit on the laptop keyboard [s]	0.074	0.074	0.071	0.071	0.069	0.068
Horizontal component of the vector of velocity of dummy's head mass centre [m/s]	9.9	9.3	8.8	8.0	7.4	6.6
Vertical component of the vector of velocity of dummy's head mass centre [m/s]	−2.4	−2.4	−1.9	−1.7	−1.6	−1.5
Resultant velocity of dummy's head mass centre [m/s]	10.1	9.5	8.9	8.3	7.6	6.8
Angle between the direction of the vector of velocity of dummy's head mass centre and the laptop plane β [deg]	13.6	14.5	12.2	12.0	21.3	22.3
Angle of the position of dummy's head (bent) relative to the laptop keyboard α [deg]	64.9	66.0	59.7	65.5	61.9	61.8

The kinematics of an adult differs from the kinematics of a child. This can be particularly well seen in the time histories of velocities (Fig. 10) and torso and head bend angles (Figs 11 and 12). Due to the small distance between bus seats, the torso of an adult hits on the computer at T = 0.033-0.062 s, before the beginning of contact between the head and the computer keyboard. The subsequent movement of the adult's body can be seen in the growing head bend angle until dummy's face hits on the surface (keyboard) of the laptop at T = 0.086-0.092 s (Table 2). A relation has been revealed here, according to which the earlier dummy's torso hits on the computer edge the later dummy's head hits on the keyboard (Fig. 10).

The course of changes in the velocity of the adult's head shows that the values of both components of this vector are comparable with each other until the head comes into contact with the computer, which indicates a specific nature of this impact. Conspicuous are very high values of the normal component at the instant of hitting on the computer: they come to a range from 6.5 m/s to 8 m/s and are about four times as high as those observed in the case of a child (cf. Tables 1 and 2).

Table 2. Summary of the values of time, velocity, and angular position of the head of dummy H III at the instant of hitting on the mobile computer

Seat spacing [m]	0.75	0.73	0.71	0.69	0.67	0.65
Instant when dummy's torso hit on the edge of the mobile computer [s]	0.062	0.057	0.051	0.045	0.049	0.033
Instant when dummy's head (face) hit on the laptop keyboard [s]	0.086	0.088	0.088	0.090	0.090	0.092
Horizontal component of the vector of velocity of dummy's head mass centre [m/s]	10.1	9.7	9.3	8.8	7.8	6.5
Vertical component of the vector of velocity of dummy's head mass centre [m/s]	−8.1	−7.9	−8.3	−7.9	−7.6	−6.6
Resultant velocity of dummy's head mass centre [m/s]	13.0	12.5	12.4	11.9	10.9	9.3
Angle between the direction of the vector of velocity of dummy's head mass centre and the laptop plane β [deg]	38.5	39.3	41.6	41.8	44.4	45.3
Angle of the position of dummy's head (bent) relative to the laptop keyboard α [deg]	41.7	29.4	24.0	11.1	6.4	1.5

The extreme values of the velocities of head impact against the computer during a road accident, presented in Tables 1 and 2, show that they depend to a considerable degree on the seat spacing.

5. Recapitulation

The test results obtained provide grounds for an assessment of the influence of the seat spacing on the danger that would arise from passenger's head (face) hitting on the surface (keyboard) or edge of a mobile computer. In particular:

- During the frontal impact of a bus against an obstacle, child's torso hits on the computer after a time of T = 0.056-0.068 s from the beginning of the bus collision process; for an adult passenger, this time is T = 0.033-0.062 s.
- This time ("delay") depends on the distance L_0 between seats; the smaller L_0, the shorter this time.
- Child's head hits on the computer with a velocity of v = 6.6-9.6 m/s and this impact has the nature of a slide.
- The velocity of the head impact against the computer rises with increasing L_0.
- At the instant of hitting on the computer, child's head changes the direction of motion and is suddenly bent backwards; the velocity of this bending is the higher the smaller L_0 is.
- The course of the impact of adult's head against the mobile computer is different from that observed in the case of a child.
- The adult restrained during an accident by a two-point seatbelt hits at first his/her torso on the computer edge; the impact of his/her head takes place only after a time of T = 0.086-0.092 s.

– During this impact, the normal component of the head velocity vector reaches a value of v = 6.5-8 m/s; such values are about four times as high as those observed when child's head hits on the computer.

The calculations presented were carried out for the bus hitting an obstacle with a velocity of v = 50 km/h. They have highlighted an important source of passenger injuries caused by the presence of various objects (such as foldable tables and mobile computers) in the space between bus seats. The calculated values of the possible velocities of hitting on such objects show that the objects may pose a real hazard for the health of bus passengers.

The full text of the article is available in Polish online on the website http://archiwummotoryzacji.pl.

Tekst artykułu w polskiej wersji językowej dostępny jest na stronie http://archiwummotoryzacji.pl.

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