This study proves that in addition to the angles between the anthropometric measurements, passenger car interior space optimization in terms of ergonomic adjustment is most heavily influenced by the totals of the anthropometric measurements for lower leg length, upper leg length and sitting height for the same overall totals, which are individually different. The regularities of the anthropometric measurement mechanism as well as their geometry and kinematics of movement have been compared with the mechanical mechanism, so that according to new methodology the vehicle has been designed for wider range of drivers. The optimal space is defined within a coordinate system with the origin at the fixed "O" point of contact between the driver's heel and the car floor in front of the accelerator pedal. The designed optimal roof-floor space height for the driver along the z-axis amounts to 1250 mm, and the distance from the fixed "O" point backwards along the x-axis is 1180 mm, while the distance from the zero point for feet accommodation forwards along the x-axis equals 330 mm. The adjustability of the seat-floor height ranges from 190 mm to 300 mm. The horizontal movement of the seat amounts to 250 mm.

Keywords: anthropometric measurement, passenger car, interior, driver

Introduction

This study is a continuation of the previous work of the present authors, where different aspects of method for investigating the anthropometric measurements of drivers of passenger vehicle with optimal ergonomic adjustment of the vehicle to man are described. The passenger car interior space dimensions depend on the range to which the car is adjusted. All previous research in literature show that this range is most commonly between the 5th percentile woman and the 95th percentile man. In paper, we have shown that extremely large anthropometric measurements can be accommodated in such limited space by reducing the seat height, whereby the overall vehicle height is decreased and the distance between the knees increased, so that the upper leg lower part surface is in full contact with the seat. Our new approach is to adjust the vehicle to drivers with anthropometric measurements ranging from the smallest for women to the largest for men, through the most critical combinations of small and large anthropometric measurements.

Sample and data

The data from longitudinal studies of anthropometric measurements in Serbian drivers are used in the passenger car interior space design in this paper, because available standards are general recommendation, while specific populations differ significantly across the time and one to another, too. Our last findings in Serbia from 2009 (Table 1) are compared with relevant research. Survey involved drivers during the technical inspection of their cars, with the clothing and shoes they were wearing under driving conditions, while static anthropometry methods were applied in this study.

Methodology and results

The mechanism of human anthropometric measurements can be viewed as analogous to a mechanical mechanism. Hence, the geometry and kinematics of movements are designed from the "O" point which is positioned in front of the accelerator pedal and is approximately fixed, and is the origin of the coordinate system with three axes: z, x, y. The mechanism only serves for a specified percentile, e.g. the 50th percentile anthropometric measurements of a man are the average measurements of an imaginary man.
Our new methodology is based on choosing those real drivers who, from the aspect of anthropometry, are the most unfavorable for the design of the optimal and minimal space respectively. The position of the driver's anthropometric measurements under driving conditions is limited not only by anthropometric measurements of dimensions, but also by angles for movements. In literature, they are most often given for specified limitations. According to the angle between the feet and the car floor $\psi = 13^\circ - 60^\circ$, the angle between the lower part of the upper leg and the horizontal $\beta = 5^\circ - 12^\circ$ and the angle between the axis passing through the ankle and the knee joints and the vertical $\gamma + \beta = 15^\circ - 37^\circ$. In our passenger car interior space design the angle between the seat backrest and the vertical is considered to be the most approximate to the angle between the axis passing through the hip and the rotating shoulder joints.

The most significant anthropometric measurements in the passenger car interior space design whose different individual measurements amount to the same total sum are sitting height, upper leg length and lower leg length, while in the construction of space for feet accommodation the lower leg length differs from the upper leg length for their equal total. The longer the legs and the higher the sitting height, the farther the hands are from the steering wheel. In this way, in addition to the limitations of optimal angles for the mechanism of anthropometric measurements accommodation, the limitation for moving the seat backwards along the x-axis is also obtained. In this study, the passenger car interior space is especially designed in the z-x plane with the above described methodology of limitations. In paper it was inferred that the key anthropometric measurements for the determination of the passenger car interior space height are the lower leg length and the sitting height of extremely large drivers and that they are functionally interconnected as parts of the mechanism. The data from Tab. 1 are correlated. It is evident from the sitting height – upper arm length relation and the sitting height – lower leg relation that the most significant linear correlation is between the sitting height and the upper leg length, with a correlation coefficient of $r_m = 0.3531$ for men and $r_w = 0.315$ for women. The correlation coefficients between the sitting height and the lower leg length are $r_m = 0.446$ and $r_w = 0.415$. Although non-linear curves could have better fitting, linear relation are always recommended in anthropometry and values in this survey are close to those in. This difference, especially for males, indicates a greater difference between the lower leg and the upper leg measurements for the same total sums of sitting heights and lower and upper leg measures. Therefore, in this regard the lower leg length is a more critical measurement in the passenger car interior space design.

It can be seen from the Table 2 that all 5 extremely large male drivers as well as an extremely small female driver drive small cars. The second limit for the range of vehicle adjustment will be obtained by means of methodology similar to that for determining the

<table>
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<tr>
<th>No. of Participants</th>
<th>Average year of birth</th>
<th>Sex</th>
<th>Weight (kg)</th>
<th>Height (mm)</th>
<th>Height when seated (mm)</th>
<th>Lower leg length (mm)</th>
<th>Upper leg length (mm)</th>
<th>Shoulder width (mm)</th>
<th>Hip width (mm)</th>
<th>Arm length (mm)</th>
<th>Foot length (mm)</th>
<th>Shoe length (mm)</th>
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<td>636.87</td>
<td>471.21</td>
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<th>Height (mm)</th>
<th>Sitting height (mm)</th>
<th>Upper leg length (mm)</th>
<th>Lower leg length (mm)</th>
<th>Shoulder width (mm)</th>
<th>Hip width (mm)</th>
<th>Arm length (mm)</th>
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anthropometric measurements of the smallest female driver. Similarly to those for men, the data are in a small dispersion limit and that by eliminating men whose totals for torso height and lower leg length are below 1320 mm, only 6 female drivers are eliminated, i.e. 3.2%. The higher percentage of the smallest anthropometric measurement elimination of females (3.2%) compared to that of males (0.62%) actually means an equal elimination percentage because in Serbia only 15% of drivers are women.

**Discussion**

The passenger car interior space design for the Serbian population

The mechanism of anthropometric measurements is accommodated in the positions taken by the driver under driving conditions by limiting the optimal angles between the anthropometric measurements and some individual measurements themselves. The height of 1250 mm is a very common measurement in smaller class vehicles. The possible variants of accommodating the driver's anthropometric measurement mechanism are given in Fig. 1. It is noticeable that for position 1 the model of man A1 with a sitting height lower than 980 mm and a lower leg length higher than 715 mm is sitting in the seat 190 mm high with a permissible 132° angle of knee joint rotation between the lower and upper leg, but an impermissibly large angle of 17° between the horizontal and the thigh bone.

When titling the backrest to a maximal inclination of 27° the head apex height is 1160 mm, while the horizontal tangent, in the torso movement forward from the hip, is at a height of 1180 mm. The reduction of the impermissibly large angle of 17° between the horizontal and the thigh bone is obtained by tilting the seat backwards, but in that case the angle of the knee joint would be increased even more from what is already a large 132° angle. If the angle between the longitudinal thigh bone axis and the horizontal is reduced to the optimal 3.5°, then the seat height in the A2 model must be raised to as much as 300 mm, whereby the knee joint angle becomes 132° and the head height 1270 mm at the backrest angle of 27°, while the horizontal tangent is at a height of 1300 mm when tilting the head forward. The position of the B1 model with a sitting height of 1020 mm at a seat height of 190 mm has a more favorable knee joint angle of 125° and a 13° angle between the horizontal and the longitudinal axis of the thigh bone. The head apex height is 1200 mm at the 27° seat angle, while the horizontal tangent in the torso rotating movement is at a height of 1240 mm. The position of model B2 at a seat height of 260 mm will have a 134° knee joint angle, but only a 2° angle between the horizontal and the longitudinal axis of the thigh bone. However, here the head apex height is at its highest, at 1270 mm, and the horizontal tangent at the torso rotating movement forward is at a height of 1300 mm. All four positions of the models have critical points: A1 has a 17° angle between the horizontal and the longitudinal axis of the thigh bone, A2 and B2 have the maximal height reaching the head apex at 1300 mm, B1 the aforementioned comparatively large height of 1240 mm and a 13° angle between the longitudinal axis of the thigh bone and the horizontal. The optimal position of a female driver in model C, with small anthropometric measurements to be used for determining the lower limits of the passenger car interior space adjustment range is provided by the 120° angle of the knee joint. The seat backrest angle of 20° provides a more favorable visual angle as well as an appropriate distance between the hands and the steering wheel (more about in 1, 2, 3). The angle of the longitudinal axis of the thigh bone is of a favorable 3.5° at a sitting height of 300 mm. The visual angles of a small woman in model C obviously coincide more with those of men in models A and B if they have lower seat heights, i.e. at a height of 190 mm. This means that optimal space can be designed for the range provided by those three models (Fig. 1) under the condition that in models A and B the problem of adequate contact between the seat area and the large length of the lower part of the upper leg is solved.

**Conclusion**

Majority of traffic accidents involves driver related factors18, so this paper aimed to adjust interior space of passenger car in more precise and accurate way. According to proposed methodology, the minimal
passenger car interior space for driver accommodation from the fixed point of the driver's heel in front of the accelerator pedal along the x-axis backwards should amount to 1180 mm, while the car floor-roof height along the z-axis should be 1250 mm. The distance for feet accommodation along the x-axis from the zero point to the shoe toe is 330 mm. Drivers achieve relative reduction of the passenger car interior space along the z-axis and of the height along the x-axis in real conditions by decreasing the seat height and simultaneously spreading the knees apart along the y-axis. For extreme totals of the upper and lower leg lengths, the passenger car interior space along the y-axis should amount to 1013 mm. The vertical seat movement along the z-axis from the car floor ranges from 190 mm for the largest males to 300 mm for the smallest females. The horizontal seat movement amounts to 250 mm.

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References