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Evaluation of the actual sitting position of drivers of passenger vehicles

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Abstract. This paper is concerned with comparing the actual sitting position of drivers of passenger vehicles with the position commonly considered optimal from the viewpoint of active and passive safety, and the long-term effects on the driver's health. The research described herein was conducted on a sample of randomly selected drivers in Czech Republic. All the measurements were conducted in a single, neutral, medium-sized passenger vehicle with which none of the test subjects had any previous experience. For this reason, none of the tested drivers had the advantage of familiarity with the environment. This research came about as an attempt to re-create the common situation wherein a driver adjusts his/her position behind the steering wheel solely on the basis, of intuition. Through a statistical evaluation of the acquired data, it was possible to confirm the initial hypothesis that a substantial portion of tested drivers assume a less than optimal driving position. This fact has a negative effect not only on reducing active and passive safety, but directly impacts upon the health of drivers who cover high annual mileage. The results of this paper can be used when designing cabins and modern interactive systems for passenger vehicles, which will be able to assist the driver in setting the optimal driving position. In this way, it will be possible to directly impact upon traffic safety and positively influence drivers' health.

Key words: Driver, Seat, Position, Sex, Physiological Optimum.

INTRODUCTION

Today the design of the cabin ergonomics of passenger vehicles is considered an ever increasingly important component of the construction process of a new vehicle (Wang et al., 2007). An optimally ergonomically designed driving seat, as well as those of the vehicle's crew, plays a considerable role primarily in the area, of vehicle safety (Reed, 1998). Modern adjustable seats enable the driver to set a whole range of geometric parameters and choose a sitting position which the driver subjectively feels to be comfortable. The optimal positioning of the seat thus directly influences the driver's feelings and overall comfort, and thereby also the safety of operation of the vehicle (Reed, 1998, Matoušek, 1998; Bhise, 2012).

The position of the driver in the seat is important from a number, of perspectives, which in certain respects are contradictory. This for example concerns requirements with regard, to active safety, with regard, to physiological comfort, passive safety and others (Tilley, 2002). This study considers the position of the driver primarily from a physiological and medical perspective, and deals with the influence of angles between the limbs on the burden placed on specific groups of muscles.

A whole range of studies have focused on measurement of the position of the driver in the vehicle (Park et al., 2016), and are described in certain norms (SAE J4004). However, they mostly concern measurement in laboratory conditions and on special measurement seats (Park et al., 2016). This study obtains precise data from a real environment, in which the observed subject is not exposed to stress by a laboratory environment and sits in an actual vehicle.

The primary objective of this work is to describe and quantity the actual position which drivers adopt in the vehicle, and, also to compare these values with the values designated as optimal (Andreoni et al., 2002). With regard, to the question of the optimal values of the individual described angles, there is a considerable lack of consensus among experts, and values very often differ depending on the used method of measurement or the angle of measurement. All the published results of optimal values were summarised in a separate study (Schmidt et al., 2013). For the purposes of this study, the values (Andreoni et al., 2002) which most closely approximate the physiological optimum were chosen (Véle, 1995). Within the framework of certain surveys engaged with ergonomics (Hruška & Jindra, 2016), it was determined that a correlation exists between the sex of the driver and ability to control the vehicle and adapt to its control and communication elements. A secondary objective of this study was to confirm the hypothesis that a correlation exists between sex and correct sitting position of the driver in the vehicle.

MATERIALS AND METHODS

Participants

100 subjects (Table 1) were obtained for the purpose, of measurement (39 women and 61 men), all from a university environment – students or graduates in technical or economic subjects. The number of participants was limited in terms of organizational capabilities. However, the number of participants when compared with other studies on the same subject, however, this number may be described as above average (Schmidt et al., 2013). Participants were selected from the ranks of students and tutors of a technical university as a group that is as uniform and homogenous as possible with respect to the participant's completed education, in order, to avoid various levels of education that would have to be taken as a parameter affecting the overall results. The age of the subjects was within the range of 18 to 65 years (average age 29 years). In all cases, it was requested and confirmed that the subjects had a driving licence authorising driving of passenger vehicles. All the subjects were also in good physical health and had no limitations in terms of their physical motor skills.

Table 1. Numbers of tested persons and their parameters in relation to measurement

	Number	Age			Number of km travelled (thousand km)		
		Average	Minimum	Maximum	Average	Minimum	Maximum
Men	61	30	19	65	192	5	800
Women	39	27	18	52	68	5	400
Total	**100**	**29**	**18**	**65**	**144**	**5**	**800**

Testing environment

The chosen testing vehicle was the Mercedes Benz C220d model range from 2016, with standard interior furnishings. The vehicle was furnished with modern, adjustable seats with mechanical movement in a lengthwise direction and electronic positioning of the height of the seat, incline of the seat and back rest (Fig. 1). The furnishing also included a mechanically configured adjustable steering wheel (Fig. 1). The vehicle can be characterised as a standard medium sized saloon model.

This vehicle was chosen because it is not very widespread type in the Czech Republic and the participants were therefore selected so that the test vehicle had no previous experience. This helped to ensure equal conditions for all participants.

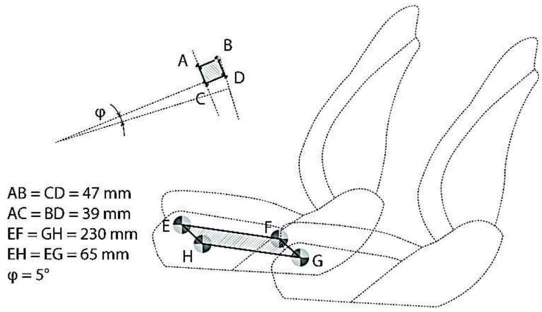

Figure 1. Positional ranges of seat and steering wheel in tested vehicle.

The vehicle was placed in a laboratory in constant conditions and at a constant temperature with a stable noise burden, so that all the subjects were under the same conditions during the test. During the measurement, the driver's door was open to the maximum position in order, to determine the maximum angle of view of the camera.

For manual data gathering a standard digital ER-05141 angle gauge was used. For electronic data gathering in the form of digital photographs, a digital compact Nikon J1 camera was used. This type of camera is equipped with a fixed lens with a focal length of 10 mm. The angle of view of the camera is 65.5°. The camera was placed on a photographic tripod with high capacity for maintaining stability at a precisely defined constant distance from the vehicle (Fig. 2).

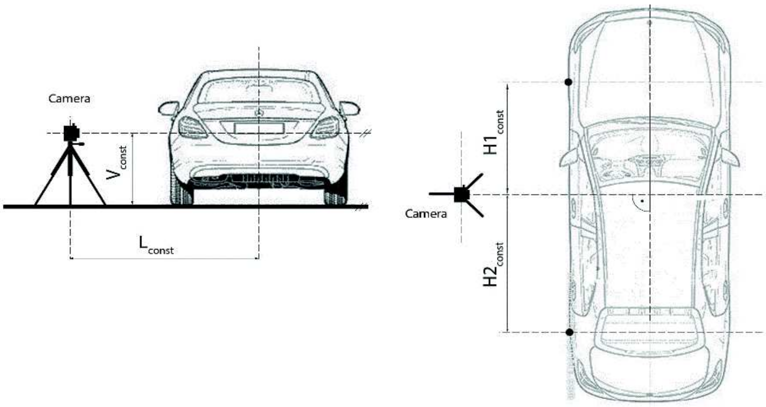

Figure 2. Diagram of measuring station with mutual position of recording camera and seat.

For secondary measurement of the mutual position of the recording device and the vehicle, a digital Bosch PLR 30 C distance gauge was used.

For adjustment of photographs and reading of values, the programs Adobe Photoshop CS6 and Adobe Illustrator CS6 were used.

Data Collection Procedures

None of the tested subjects had any prior experience with the testing vehicle. Each tested subject was thoroughly trained and familiarised with the control systems of the position of the seat and steering wheel before sitting in the measuring vehicle. After sitting in the tested vehicle, each tested subject was given sufficient time to test out and understand all the functions necessary for controlling the position of the seat and steering wheel. Before the actual measurement each tested subject was asked whether they considered their position in the vehicle to be comfortable, and whether this position corresponded to the maximum extent to the position which they usually assumed when driving a vehicle.

Each tested subject was subsequently indicated with tangent points which were placed on the locations of the elbow joint (*articulatio cubiti*), knee (*articulatio genus*), shoulder (*articulatio humeri*) and hip joint (*articulatio coxae*). The tested person was then instructed to place their hands in a neutral position on the steering wheel according, to 9 and 3 on the clock face, with loosely hanging arms without tension (Fig. 3). The measurement took place always on the left side of the body, because the tested position was always laterally symmetrical. Recording and manual measurement always took place on a frontal plane and the individual angles were recorded on a sagittal plane.

Figure 3. Tested subject, photographed in measurement position with designated flowlines of joints.

After a digital photograph has been obtained, each tested subject was manually measured with the aid of the above-stated instruments, always by the same employee, in order to ensure that the measurement method was always the same. The angles *alpha* (*articulatio cubiti*), *beta* (*articulatio genus*) and *gamma* (*articulatio coxae*) were measured manually (Fig. 4), as well as the basic anthropometric data on the tested subjects (Fig. 5), which is recorded in Table 2.

After the end of measurement, all the obtained photographs were digitally analysed and the values of the *delta* (*articulatio humeri*) and *epsilon* angles were determined, which was not possible using the method of manual measurement. For greater precision of data, the values of the angles *alpha, beta* and *gamma* was used, obtained by an averaging of both methods of measurement – manual measurement and digital analysis of photographs. The values of the angles obtained by both methods of measurement differed on average by only 4%, and it is therefore possible to state that both methods of measurement were sufficiently precise.

Some theoretical studies (Schmidt et al., 2013) use a number, of separate points in the area, of the spine, and measure the mutual angle of their flowlines. However, the shape of the spine when sitting and driving a passenger vehicle is predominantly defined by the shape of the backrest of the seat and as, a result the shape of the spine is overlooked for the purposes of this study. Only the overall incline of the torso is measured, defined by the angle *epsilon* (Fig. 4).

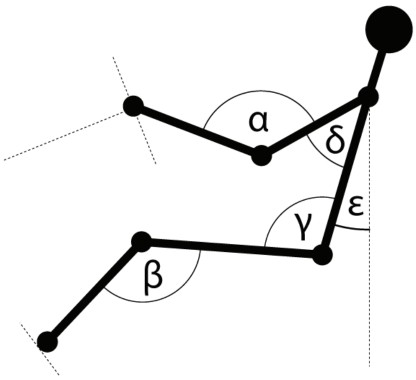

Figure 4. Diagram of measured values.

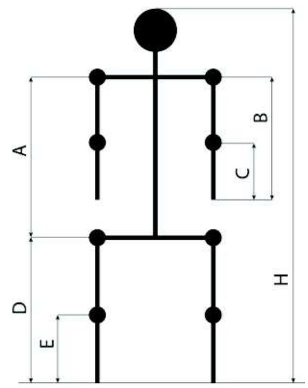

Figure 5. Anthropometric data.

Table 2. Basic measured anthropometric data of tested subjects as illustrated in Fig. 5

Dimension	Women			Men		
	average	min	max	average	min	max
A (cm)	57	51	63	63	57	71
B (cm)	45	39	52	49	40	60
C (cm)	31	26	35	34	29	39
D (cm)	97	83	103	103	92	116
E (cm)	47	39	51	48	40	60
H (cm)	170	159	180	184	171	201

RESULTS AND DISCUSSION

The results obtained during the measurement were statistically processed and evaluated using contingency tables and a Pearson's chi-squared test. The statistical averages and extremes obtained from the measured data are presented in Table 3. The obtained values were classified into three categories according, to whether they were located, in the selected optimal values, or were lower or higher. The contingency table (Table 4) presents the values for men and women separately. Table 5 presents the values of the recalculated frequencies of the individual angles, again separately for men and women.

Table 3. Resulting values of measured data of tested subjects as illustrated in Fig. 4

Angle	Optimum	Women			Men		
		average	min	max	average	min	max
Alpha (°)	105–125	113	89	141	128	101	160
Beta (°)	123–149	124	110	135	125	105	151
Gamma (°)	89–99	101	90	112	99	88	117
Delta (°)	22–42	27	14	36	35	20	51
Epsilon (°)	15–20	21	14	25	21	14	30

Table 4. Contingency tables (processed into row) of measured values for individual angles, divided according to sex

Angle	Women (number of subjects)			Men (number of subjects)		
	below	within optimum	above	below	within optimum	above
Alpha (°)	9	25	5	3	24	34
Beta (°)	18	21	0	28	32	1
Gamma (°)	0	14	25	0	34	27
Delta (°)	2	37	0	2	44	15
Epsilon (°)	1	15	23	4	27	30

Table 5. Difference in frequencies of individual angles according, to zero hypothesis for men and women expressed in percentages

Angle	Women			Men		
	below	within optimum	above	below	within optimum	above
Alpha (°)	92%	31%	-67%	-59%	-20%	43%
Beta (°)	0%	2%	-100%	0%	-1%	64%
Gamma (°)	-	-25%	23%	-	16%	-15%
Delta (°)	28%	17%	-100%	-18%	-11%	64%
Epsilon (°)	-49%	-8%	11%	31%	5%	-7%

In the case of 17 men and 3 women, extreme values of the positioning of the steering wheel were reached, with the tested subjects stating the range of adjustment of the steering wheel as insufficient. This had an influence on the optimal position, which could therefore not be attained. However, from the perspective of these parameters the tested vehicle ranks among the best on the market, and as, a result it is possible to expect that these subjects would have a similar problem in the great majority of vehicles of a similar category. This expectation was also confirmed by all the tested subjects.

From the data stated in Table 4 and in Table 5 it is evident that the greatest deviations from the optimal values are reached by men in the angles *alpha* and *epsilon*. A certain connection exists between these angles, which can be loosely interpreted as meaning that if the angle *epsilon* exceeds the optimal values, these values will most probably also be exceeded by the angle *alpha*. These angles are extremely important from the perspective of the entire postural system of the driver.

From a physiological perspective the values of the *alpha* angle are especially significant if they exceed the values selected as optimum (Table 3). Even a small exceeding of the upper limit (125°) may lead to substantial overloading of the *musculus biceps brachii* (Véle, 1995). In general, it is possible to state that the lesser the angle *alpha*, the more appropriate this position (Véle, 1995). The value of the *delta* angle is connected directly with the *alpha* angle, and here also it applies that if the upper limit of the optimal range (44°) is exceeded, there is an overloading of the *musculus biceps brachii*, with an attendant overloading of the *musculus triceps brachii* and the *musculus levator scapulae*. In the case of the *gamma* angle, exceeding of the upper limit (99°) represents an increased burden on the *musculus iliacus* and *musculus iliopsoas*. In the case of values above 110°, the significance of support for the lumbar section of the spine on the back of the seat is practically annulled, and the entire weight of the body is significantly placed on the *gluteus medius* and *gluteus maximus*.

For testing of the correlation between the sex of the tested subjects and the optimal value of spontaneously chosen angle, a Pearson's chi-squared test was used. This test serves to determine the dependency between various divisions into categories. It measures the standardised difference between actual feelings of objects which fall within the selected combination of categories and the numbers of subjects who would fit into these combinations on the precondition of independence. The sum of the standardised differences is then compared with the critical value of division X^2 on the selected level of significance (as standard 95%). The number of degrees of latitude of division is determined by the product by one reduced number of categories of both selected divisions into categories.

Table 6 summarises the statistical significance of attaining the optimal angles depending on the sex of the tested subjects. For each of the contingency tables the measured value of X^2 is stated and compared with the critical value of division by two degrees of latitude on the level of significance of 0.95. The *gamma* angle reaches only values within the optimum and above, as, a result the table and the critical value of division has one degree of latitude less.

Table 6. Values of Pearson's chi-squared test of dependency of individual angles on sex

Angle	X^2	Critical value	Cramer V	Result
Alpha (°)	20.75	5.99	0.45	Dependency
Beta (°)	0.65	5.99	0.08	No dependency
Gamma (°)	3.75	3.84	0.19	No dependency
Delta (°)	11.31	5.99	0.33	Dependency
Epsilon (°)	1.38	5.99	0.11	No dependency

The level of dependency was also measured by Cramer's V. On the basis, of the calculated values, it is possible to designate the dependency of the *alpha* angle as fundamental and the dependency of the *delta* angle as medium. This can be interpreted to mean that a difference exists between women and men, especially in the configuration of the mutual position of the steering wheel and upper part of the body. In this respect women have a tendency, to sit closer to the steering wheel, with their arms more flexed and relaxed.

Explanation of this situation can be found in generally different anthropometric parameters of men and women. As mentioned above, in the case of 17 men, stating the range of adjustment of the steering wheel as insufficient. Compared to this, on average, shorter female limbs forces women to take a position closer to the dashboard, the space in which it can be sufficiently set and steering wheel position.

The main contribution of this thesis may be regarded in the quantity of tested subjects and the involvement of a gender factor. In comparison with the present thesis, such a large group of tested persons has not been applied in any studies concerned with research in similar themes in the last 20 years. By way of example, Andreoni uses 8 persons (Andreoni et al., 2002), Kyung uses 38 persons (Kyung & Nussbaum, 2002), and Hanson 38 persons (Hanson et al., 2006), or these studies do not analyse the European population, e.g. Park (Park et al., 2016), who uses 43 persons, though all of them were of Korean nationality. The last extensive study on this theme was written in the year 1940, testing as many as 250 persons (Lay & Fischer, 1940). Needless, to say the development of passenger cars never stops and parameters of cars and the interior equipment have changed considerably in the past 20 years. Accordingly, it may be argued that results delineated in this thesis have the potential to improve and update the understanding of problems of optimization of the driver's position in passenger cars.

CONCLUSIONS

Within the framework of this study we succeeded in obtaining a large quantity of valuable primary data from a relatively homogenous group of respondents, which may be statistically relevant from the perspective of applicable comparisons with other statistics which may have been obtained from respondents with other parameters, such as those with different education, age etc. By dividing the data with the aid of contingency tables it was determined that a significant group of respondents assume a position behind the steering wheel which on the basis, of the selected comparative parameters cannot be designated as optimal.

This finding could be used for the development of automatic processes of configuration of the seat, according, to the entered parameters of the driver, into a position which would be defined as optimal. This would bring about an elimination of the human factor, which, as is evident from the above results, is defective in these processes.

On the basis, of the above results, it is further possible to state that the hypothesis stated in the introduction to the study is in large part confirmed. Statistically significant differences exist in the position assumed when driving a passenger vehicle between men and women. The explanation of this phenomenon can be considered, to be the generally more responsible approach of women to driving a passenger vehicle.

The results presented in this study could serve as a basis for further research, which would assist in further specifying the observations stated above. The data and hypotheses presented in this study could serve as factors aiding in the process of designing automobiles, with reference, to the potential target groups of customers.

It is evident that especially within the area of adjustable steering wheels it is necessary to provide a wider range of movement than is currently available in vehicles. A statistically significant proportion of drivers are unable to attain a position which could be designated as optimal due to insufficient adjustment of the steering wheel.

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