ERGONOMY OF THE INSIDE OF A MOTORCAR CABIN USED BY A PERSON WITH LOCOMOTIVE DISABILITY – A CASE STUDY PART I. ANTHROPOMETRIC ANALYSIS

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Abstract

The study discusses results of investigations carried out in the course of driving a motorcar by a person with a locomotive disability. Driving tests were conducted in road conditions as well as on a manoeuvring square. Observations concerned interactions of the disabled person during his/her utilisation of different pieces of equipment situated within the reach of the user's hands. The scope of the performed analysis covered investigations concerning somatic and receptor relationships in the man – technical means system and, to a lesser extent, dealt with the psychological aspects of vehicle driving. The investigations employed selected methods of identification of expectations from direst users – video registration. Initial investigations were carried out for one person with a locomotive disability (paraplegia). Driver's positions when performing various manoeuvres were initially compared with standard data (access to the comfort zone or comfort angles). The final result of initial experiments is a description of the adjustment of the vehicle with equipment (manually-operated accelerator - brake) to the requirements of the driver with a locomotive disability. Moreover, the authors also give a list of operations, performed in the car, which require either assistance using technical means or redesigning in the motorcar.

Keywords: *personal car, a driver with a locomotive disability, video registration of traffic, motorcar instrumentation*

1. Introduction

Selecting a car for a person with disability

Restrictions of possibilities to drive a car can be caused by an accident, anatomical changes, diseases or aging processes. Persons with restricted locomotive abilities are aided by additional assistive technology in order to adjust the already existing means, e.g. personal cars, to changes in executive systems (effectors) of the disabled person.

When designing assistive technology for this group of persons, it must be remembered that the degree of variations in anthropometric measurements of users with disability is considerable and exhibits a different variability than in able-bodied persons [9]. One of the important factors affecting the designing process is the diversity of anthropometric measurements in populations of different countries, professional groups, age intervals, social groups etc. (see, e.g. [9]). New groups of users appearing on the market (e.g. elderly people, persons with locomotive disabilities) make it necessary for the car industry to become interested in these groups of buyers. It is evident from demographic investigations that very soon drivers over 65 years of age will constitute 1/3 of all drivers of personal cars. At present in Germany, the mean age of a personal car buyer is 50.2 years (at the total car sale of 1.65 million in 2006), of which buyers over 60 years of age make up 29% (19.5% - buyers of 60-65 years of age and 9.5% - buyers over 70 years of age) [1]. It is also worth mentioning here that this group represents buyers of more expensive cars. Car manufactures become increasingly interested in the specificity of the elderly. Due to a relatively small group of persons with a locomotive disability at pre-working and working age, it would be difficult to expect such tendency in designing since it is economically unfeasible.

According to the Main Statistical Office (GUS), the number of disabled persons in Poland exceeds 5 million and it is estimated that 200 to 300 thousand of them are persons suffering from significant locomotive disability. In 2007 only about 350 new cars factory-adjusted for persons with considerable locomotive disability were sold in Poland. However, it is estimated that potentially there are still 200 thousand disabled users of personal cars [6]. Appropriate legal regulations make it necessary for a person with physical disability to purchase a car designed for able-bodied persons and only later, after the production process, have the car adjusted to his/her disability. There are many limitations, when choosing, by a person with disability, a standard car which would next meet appropriate functional requirements. A fully conscious selection of a car and specialistic equipment can be difficult and complicated due to limited amount of information which is scattered (about equipment, detailed technical parameters, such as, e.g. maximal forces needed to operate individual elements of the driving system). Tests of cars for persons with disabilities are published in Polish literature extremely rarely (one such example is a short test of four cars [5]).

In the course of the designing process of technical means for persons with disabilities, requirements directly affecting the utilisation of the product are of paramount importance. They include: functional, reliability, dynamic, ergonomic and aesthetic as well as cultural and ecological requirements. The final choice usually depends on economic limitations. In the remaining cases, economic, technological, legal and standardisation requirements affect the production process. From the point of view of a user with a disability, his/her individual requirements are important as they ensure appropriate working parameters of the device adjusted to his/her individual needs.

Frequently it is customers' conformity which causes that, at the current development of the existing products, part of the needs is difficult to become conscious of. In such situations, the analysis of recorded film sequences of an individual driver of a known product makes it possible to discover the need for new functions and novel design requirements [10]. Figure 1 presents techniques possible to employ in order to identify requirements.

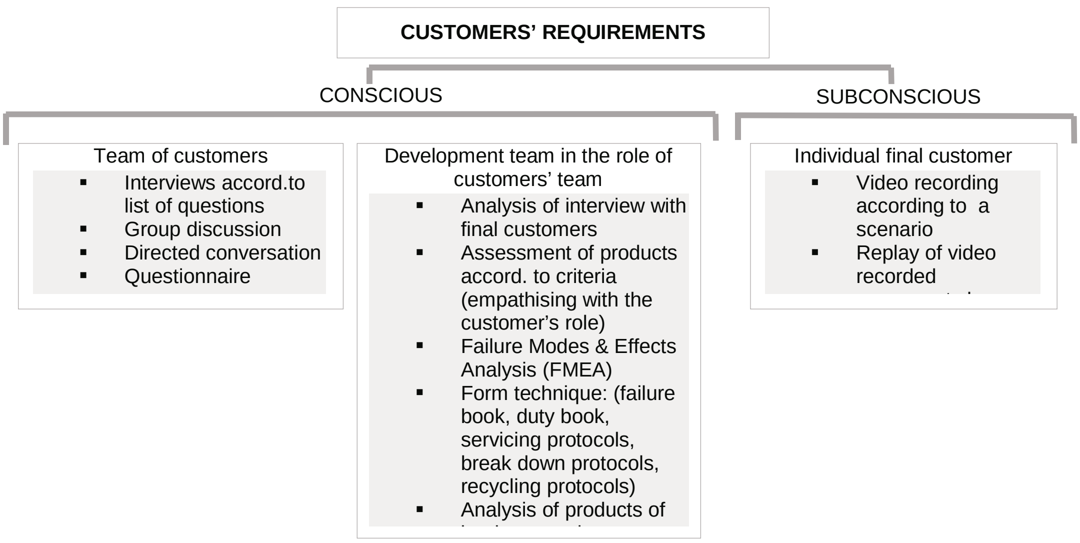

Fig. 1. Techniques allowing identification of customers' requirements

The presented issues were divided into two parts. In the course of the first part, an attempt was made to identify subconscious requirements employing the technique of video recording. In the second part, the authors tried to identify conscious needs and employed the interview technique according to a list of questions.

Measurement of comfort

Investigations of the driver's discomfort require first determination of the comfort function. The state of discomfort can be determined by comparison with an uncomfortable situation. Most frequently, this type of considerations have been and are of qualitative nature (individual sensations) without specification of quantitative data. Researchers suggest that comfort, understood as the study of somatic relationships, depends on bending angles of the human body and forces applied to these segments, on movement monotony as well as many other factors of indirect influence (age, gender, disease, kind and degree of disability, training, fatigue, posture, road conditions, etc.). Discomfort of the entire body can be caused by the discomfort of one of its segments [2].

2. Methodology

Investigations

The following three experiments were carried out: (1) video recording of the driving process in urban and non-urban conditions, (2) questionnaire assessment of the seat geometry, (3) questionnaire assessment of the felt discomfort. The last two experiments are discussed in the second part of this research project.

The investigations were conducted using a personal car from segment D equipped in additional instrumentation, namely manual accelerator and brake as well as an RGH II (manual acceleration-brake) device of Cebron Company. In addition, the vehicle had an automatic gear box. The authors employed a car used by a disabled person in order to eliminate the need of getting the person accustomed to new conditions of internal space and handling of instrumentation.

Before investigations of the car driving process began, anthropometric measurements of the user's dimensions were performed and basic data (descriptive label) about the user were obtained (Tab. 1).

Tab. 1. Driver's characteristics

Parameter	Value
Age	32 years of age
Height	182 cm
Weight	72 kg
Height of the spinal column injury	Th5

The driver who took part in experiments had a 4-year experience in driving a number of adjusted personal cars and, consequently, developed repeatable and stable motion habits realised during the described experiments.

The described experiments were conducted employing the method of direct observations followed by another observation of the material recorded on a camcorder. Information concerning improper adjustments was obtained comparing images from the camcorder with standard data (about angles of comfort, comfort zones).

Experimental conditions

In their investigations, the authors employed techniques of identification of customers' expectations (Fig. 1). In the course of the first stage of experiments, research methods of subconscious requirements were employed using for this purpose three camcorders situated in three different places in the car cabin (Fig. 2). The camcorders were distributed in places which would allow later the analysis of somatic relations of the driver. They allowed registration of the driver's behaviour from two orthogonal directions (observation of the midsagittal plane – camcorder No. 2 and a fragment of the horizontal plane – camcorder No. 3) as well as the field of vision in front of the car (camcorder No. 1). Camcorder No. 2 recorded the view in a system revered by 90° to the right from the vertical position.

Experiments were conducted in two stages. The first test was carried out in conditions of urban traffic and on a manoeuvring square (about 2 hours of driving); the test was supplemented with observations accompanied by video recording during about 6 hours of driving.

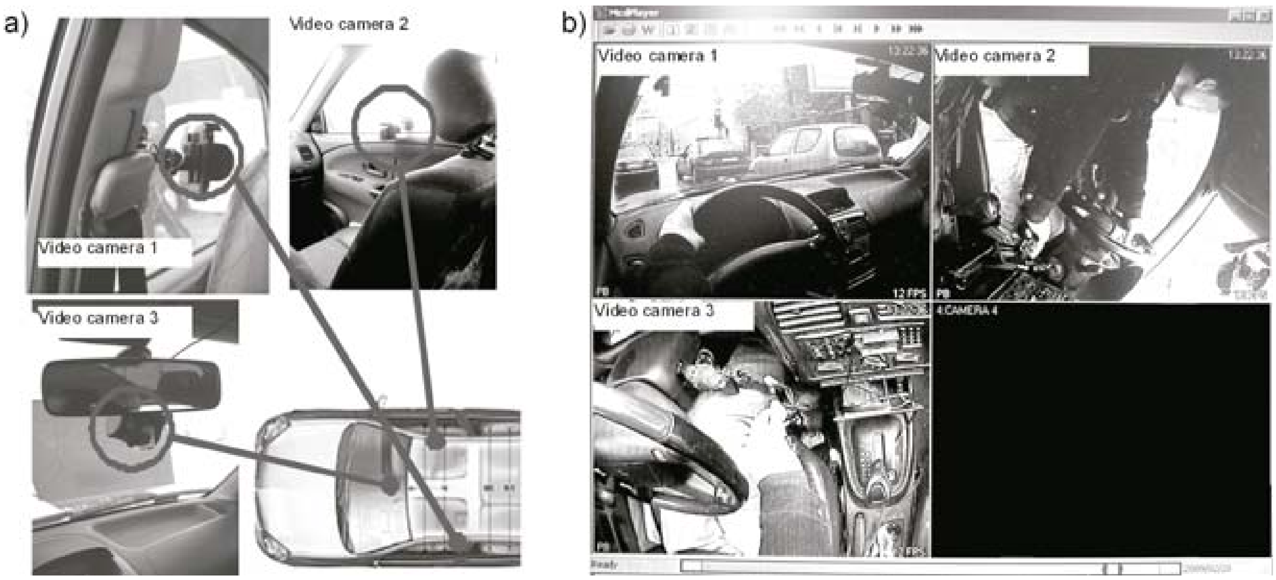

Fig. 2. Distribution of camcorders inside the car (a) and example images from recordings (b)

In order to find the most comfortable positions of all elements in the car cabin, before driving the following regulation procedures were performed: (1) driver's seat regulation, (2) regulation of the steering wheel, (3) regulation of the remaining elements, (4) regulation to correct initial dependent settings (mutual position of the steering wheel and driver's seat).

The following recommendations for the appropriate position settings were applied in the course of regulations:

- Tilt angle of the driver's seat backrest 20° to 30° or set it almost vertically,
- Move the driver's seat back so that hands hold the steering wheel lightly,
- Adjust the remaining regulations of the driver's seat (height of the seat, lumbar support, regulation of the headrest etc.),
- With his arms completely stretched, the driver should be able to place his/her wrists on the steering wheel at 12 o'clock,
- When driving, arms should be bent (the angle between the body segments: arm and forearm should be about 20° to 30°),
- At this position, the driver's back should press firmly against the backrest and the bodyweight should rest on the seat,
- Legs should have sufficient space (appropriately far from the bottom side of the dashboard, optimal angle of bending – 95° to 135° (DIN 33408),
- Adjust the position of the steering wheel,
- Adjust the position of the driver's seat again after adjusting the position of the steering wheel (if necessary).

The position of the person with a locomotive disability should be as follows: left hand placed on the steering wheel (at nine-ten o'clock), right hand holding the manual accelerator-brake lever.

Naturally, the actual position will depend on individual requirements of the driver.

3. Results of video recording and their analysis

The performed tests allowed collecting information about the ergonomics of the inside of the driver's cabin. The performed investigations provided information about inconveniences occurring both during road traffic situations as well as during manoeuvres on the parking lot or operations inside the cabin when parked. Simulations of major manoeuvring activities were carried out allowing the identification of types of behaviour of the driver with locomotive disabilities which differed from those of the able-bodied driver. Those differences stemmed, among others, from the movement limitations of the driver's trunk as well as the necessity to handle additional equipment (manual accelerator and brake).

Several video shots from the registered material important from the point of view of analysis were selected which showed such activities as: braking (Fig. 3), backing up (Fig. 4) and handling of the central dashboard, passenger door and the glove box in front of the passenger's seat (Fig. 5).

Fig. 3. Braking: a) main brake, b) handbrake

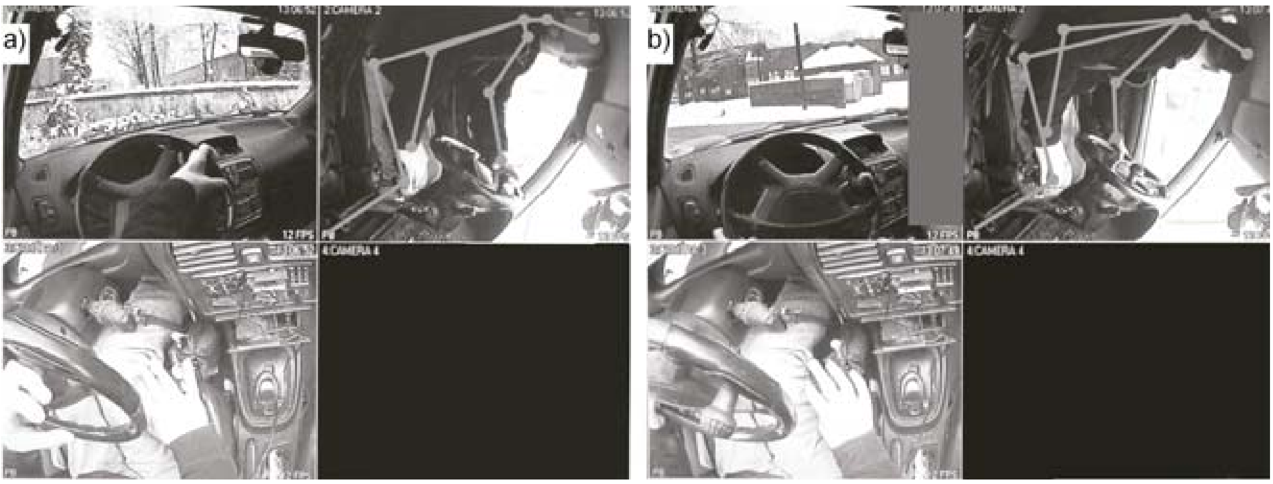

Fig. 4. Backing up: a) turning the head over the right shoulder – observation of the rear, b) turning the head over the left shoulder – observation of the rear

In Figures 3-5 showing views from three camcorders additional information was provided about approximate position of the driver's body joints (marked with grey colour). Figure 3 (view from camcorder 2) also shows the outline of body segments forming the view of the driver's silhouette template. Information marked in Figure 3 with grey colour (positions of joints and driver's silhouette) was utilised in further analyses (Figs. 7 and 8).

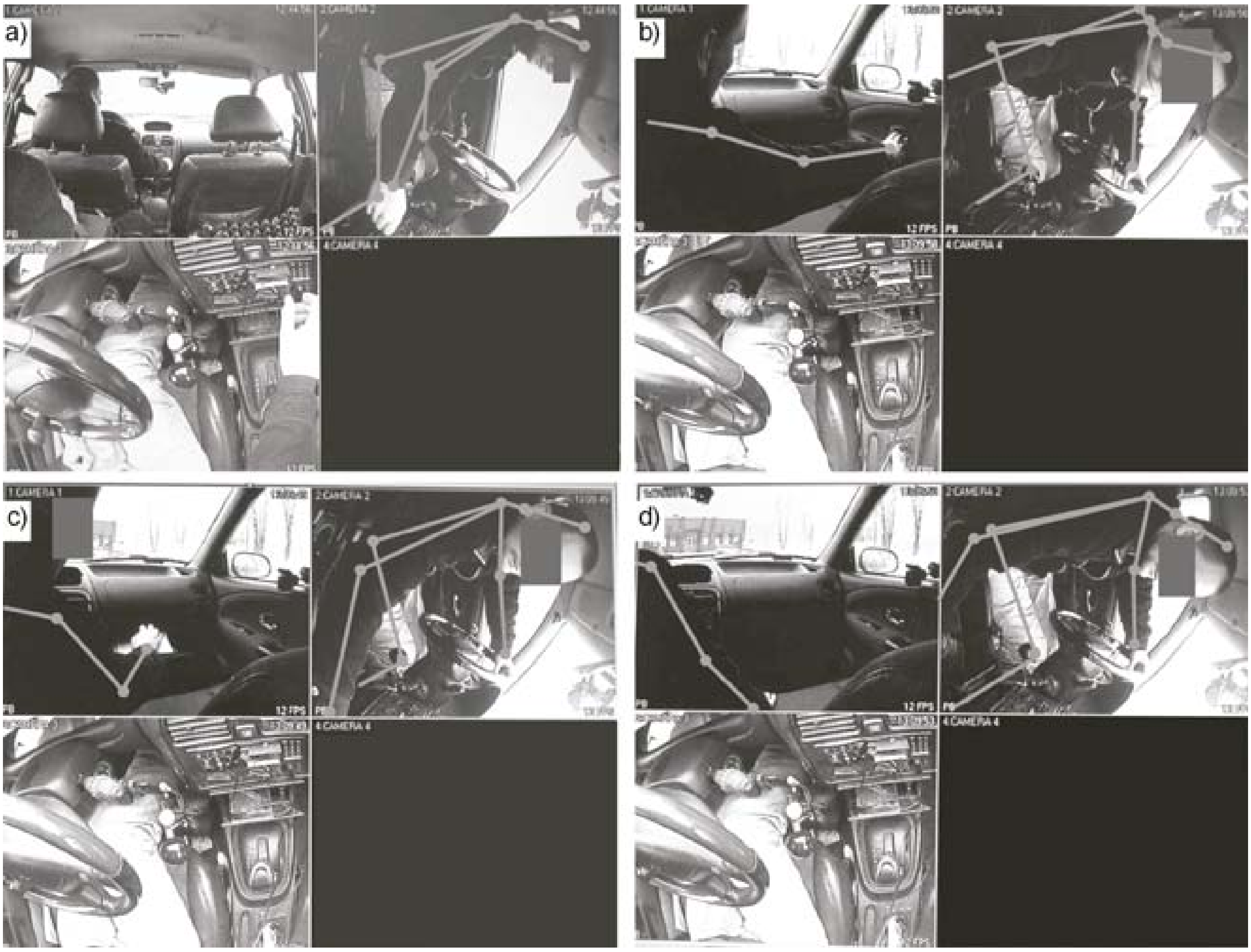

Fig. 5. Other activities performed in the area of the central dashboard and passenger seat: a) operating the radio, b) opening the passenger door, c, d) handling of the glove box

The recorded driver's adopted position in the analysed situation (outline of the driver from video recording – Fig. 3a, camcorder 2) reveals certain deviations in comparison with the position recommended by the DIN 334080 standard (Fig. 6). The need to hold the right hand on the manual accelerator – brake lever changes the angle of comfort of the body segments arm – forearm.

The performed analyses of the video-recorded materials using 2D templates in the CAD program allowed initial identification of the following irregularities occurring during driving:

- The RGH II lever is situated in a place which forces the driver to separate the shoulder-blades from the backrest (when pushing the lever forward – braking) and changes the angles of comfort between arm-forearm segments (Fig. 3),
- During driving, it is not possible to hold the steering wheel with both hands all the time – handling the RGH II lever makes it necessary to take the right hand away from the steering wheel. A relatively long distance of the RGH II lever from the steering wheel increases the reaction time.
- The RGH II lever can be operated only with the right hand.
- Backing up is performed without turning the head back (using only the side rear-mirrors) (Fig. 4) – poor trunk stability fails to ensure full turn around.

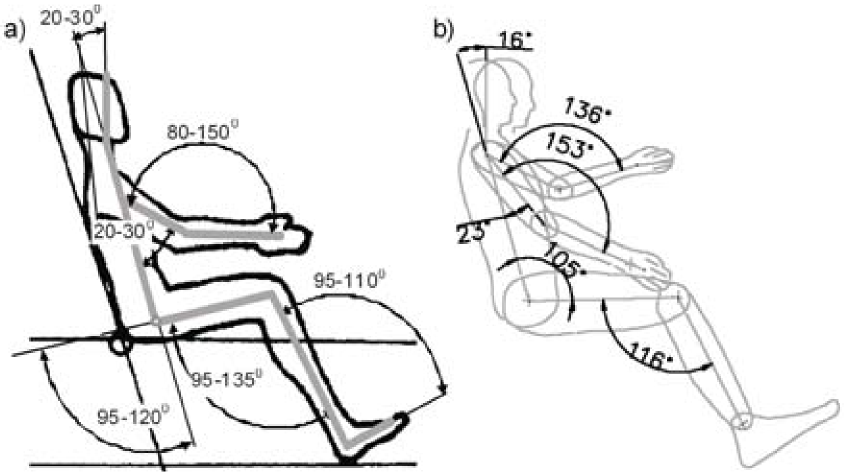

Fig. 6. Angles of comfort in accordance with recommendations (a) and angles of comfort of the driver with disability (b)

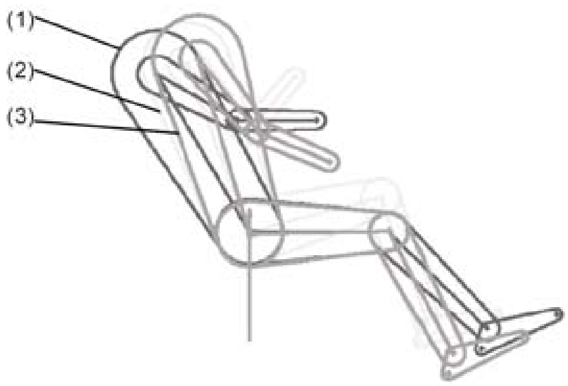

Fig. 7. Extreme recommended positions resulting from angles of comfort (1) and (2) and angles of comfort of the driver with disability (3)

- The use of the glove box in front of the passenger's seat is difficult – in order to keep balance when reaching towards the glove box, the driver must hold tight to the steering wheel with the other hand; regaining the driving position requires propping up against the passenger seat (Figs. 5c and d). Opening of the passenger's door is possible but requires a stable propping up of the left hand on the passenger seat (Fig. 5b).
- There is a slight limitation of the space for legs by the RGH II device.
- Changing of the hand position on the steering wheel when operating it with one hand results in a momentary lack of contact with the wheel during turning.
- Turning with a simultaneous switching on of indicators requires a careful coordination of the steering wheel rotation with the switching on of indicators and holding the knob fixed to the steering wheel to ensure its continuous rotation with one hand without "changing hands". There is a problem with angular determination of the position of the steering wheel without following the position of the knob on the wheel (sight fixed on the road).
- Greater number of necessary operations to be performed by upper limbs changes the working conditions of upper limbs (the left hand rests on the steering wheel and the right hand handles all levers: manual accelerator-brake, gear, hand brake).
- Asymmetrical loading of the driver reduces the comfort of driving,
- Increased trunk stability is achieved by resting the forearm and elbow in the area of the lower edge of the window.

It can be acknowledged that the handling of the dashboard and the centre tunnel is ergonomic (radio, gear lever, hand brake – see Figs. 3b, 5a).

4. Recapitulation

The technical means which is employed most commonly in Poland for manual control of vehicles is the RGH II device used in the described investigations and which is manufactured by Cebron Company. There are numerous other appliances fulfilling identical functions [7] differing with: the placement of control elements, degree of coupling with electronic systems of the car or adjustment to various disabilities (e.g. limited strength and manipulation possibilities of the hand make it essential to change zones of driver-car interactions). Better ergonomics of assistive technologies can be achieved when the assisting devices are situated as close as possible to the zones of comfort existing in the car and which are associated with driving. For instance, application of the accelerator in the area under or over the steering wheel does not make it necessary to take the right hand off the steering wheel during acceleration [7].

In the case of the utilisation of the tested car by the driver with locomotive disability there were only rare occasions when the driver could put both hands on the steering wheel. The lever of the RGH II device is operated by the central part of the hand and fingers are placed on the elements of the appliance.

Generally speaking, the employed instrumentation of control-monitoring devices fulfilled their functions properly. The placement of the knob and the lack of possibilities to change its position raise doubts. The trunk stability is also unsatisfactory, especially in situations when it is necessary to turn or tilt the trunk considerably which results in excessive loading of arms. In addition, arm loading during driving is considerable in persons with locomotive disabilities due to the need of trunk stabilisation with arms (especially important when turning corners).

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References

[1] Dudenhoeffer, F., *Demografie und Innovation*, Jahrgang 110, ATZ 01/2008.
[2] Marler, T., Rahmatalla, S., Shanahan, M., Abdel-Malek, K., *A New Discomfort Function for Optimization-Based Posture Prediction*, SAE Human Modeling for Design and Engineering Conference, Iowa City, IA. Society of Automotive Engineers, Warrendale, PA. SAE paper 2005-01-2680, 2005.
[3] Nowak, E., Kalik, E., *Antropometria na potrzeby osób starszych i niepełnosprawnych – dane do projektowania*, Wyd. Instytutu Wzornictwa Przemysłowego, Warszawa, 2003.
[4] Pahl, G., Beitz, W., Nauka konstruowania. WNT, Warszawa, 1984.
[5] Smoleń, M., Magdziak, R., *Szansa na jazdę*, AutoMotor, pp. 54-59, 7/2008.
[6] Smoleń, M., *Precyzyjna pomoc*, rozmowa z A. Wojtowicz-Pomierną, AutoMotor, p. 61,7/2008.
[7] Sydor, M., *Analiza funkcjonalności urządzeń adaptujących samochód osobowy do potrzeb niepełnosprawnego kierowcy*, chapter in monograph Ergonomia Niepełnosprawnym, Wyd. Politechnika Łódzka, Łódź, 2006.
[8] Tarnowski, W., Podstawy projektowania technicznego, WNT, Warszawa, 1997.
[9] Zabłocki, M, Rychlik, M., Branowski, B., *Zasady ergonomii w projektowaniu samochodu*, chapter in monograph Ergonomia produktu. Zasady projektowania, Wyd. Politechniki Poznańskiej, Poznań, 2006.
[10] Zabłocki, M., *Metodyka projektowania urządzeń technicznych dla osób niepełnosprawnych*, doktor thesis, WMRiT, Poznań, 2002.