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# APPLICATION OF VIRTUAL MANNEQUINS IN THE PROCESS OF DESIGN AND EVALUATION OF MODULAR WHEELCHAIR

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**Abstract**. *Patients with cerebral palsy need different wheelchairs for inside and outside use. On the other hand, children with cerebral palsy are growing up and the necessity for bigger wheelchairs becomes an economic problem for their families. In order to meet the needs of these children we propose a model of adjustable modular wheelchairs. Using ergonomic methods and appropriate anthropometric measurements of children we have established the ranges of adjustable dimensions for seat for children of age between 7 and 14 years. On the basis of these dimensions a model of an adjustable seat for wheelchair is made. Using the principle of modularity the seat is designed to be adjustable in several dimensions: seat height, backrest height, headrest height, armrests height and distance and footrests height and distance. The principle of modularity is also applied in the possibility to place the seat on different driving structures. Virtual 3D model of the wheelchair is evaluated by virtual mannequins in several different positions: dimensional comfort in sitting and standing positions, zones of convenient reach for seated patient and also hand reach comfort for the companion person who drives the wheelchair.*

**Key words**: *Anthropometrics, Ergonomics, Modularity, Virtual Mannequin, Wheelchair*

## 1. INTRODUCTION

Cerebral palsy is a result of brain injury causing impairments of the locomotion system, the body balance and coordination [1]. Most of the patients with cerebral palsy have different kinds of spasms of the body. Almost all of them are characterized by individual physical and intellectual conditions. Every patient has to be treated with different types of medical treatments. One of the most important treatments is positioning of the patient's body in a stable and regular posture. This is possible with a special seat with accessories for stabilization of the patient's body. In most of the cases, these treatments are very successful. Because of this fact, the seat design is of a great importance for these patients. On the other hand, the fact is that these children are undergoing the period of growth, from

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the birth to the end of the teenage years, so they need bigger seats almost every year. This is a big economic problem for their families.

The main goal of our research, made in cooperation with "Slavej AD" Center for orthopedic prosthetics from Skopje, is to find the best solution of wheelchair design in order to meet the needs of the children with cerebral palsy. After the considerable anthropometric and ergonomic research we propose the concept of modular wheelchair consisting of two main parts: seat and driving structure. The advantage of this concept is a possibility for combining the seat with different driving structures in order to provide for better flexibility of use in different spaces. We also propose a modular seat consisting of several adjustable parts in order to follow the changes of the child's body and with the possibility of putting other accessories for performing different tasks.

## 2. DESIGN REQUIREMENTS

Initially we set up the target group of users: children with cerebral palsy between 7 and 14 years of age. We defined that the main purpose of the wheelchair is to perform as many activities of the children with cerebral palsy as possible. The main goal of the proposed idea for modular wheelchair is improvement of the life of the children with cerebral palsy.

In order to provide the best solution we made several surveys: survey of the market requirements, anthropometric survey of the target group, survey of the ergonomic requirements.

### 2.1. Market survey

There are many kinds and types of wheelchairs with different driving systems and different purposes on the market. According to the experience of the stuff of "Slavej AD" Center for orthopedic prosthetics from Skopje and medical stuff of the Orthopedic Department at the Faculty of Medicine in Skopje, we established the design requirements on the basis of three different aspects:

Medical requirements:
- the wheelchair should provide firm posture of the spine;
- the angle between the body and the lower limbs must be $90^0$;
- the head must have support for obtaining proper position;
- the seat must be soft in order to avoid wounds;
- possibility to add medical treatment accessories;
- dimensions of the seat must be appropriate for the child’s dimensions.

Customer requirements:
- low price;
- low weight;
- easy to use;
- easy to put in vehicle;
- easy to change positions;
- easy to dissemble;
- comfortable enough for all day seating;
- possible of use in different spaces;

- suitable for performing as many activities as possible;
- a good and pleasant design;
- possibility to buy and add different accessories for everyday tasks;
- long period of exploitation;
- possibility of changing parts because of damaging.

Requirements of manufacturer:

- low production price;
- low market price;
- modular parts for better and easier reparation;
- modular accessories for extra activities which could be sold separately.

### 2.2 Anthropometric analysis of sitting in wheelchair

In order to solve the problem of seat design it is necessary to make anthropometric analysis of the target group: children with cerebral palsy between 7 and 14 years of age. The definition of dimensions as well as of the ranges of adjustability for all the wheelchair parts is the main goal of our anthropometric analysis. One of the biggest problems is how to find proper sources of anthropometric measurements. There are many anthropometric sources for children without disabilities, but very few for the disabled. Because of a great variability of dimensions of children with cerebral palsy [3] in different conditions, we have decided to use measurements for children without disabilities between 7 and 14 years of age [2]. The measurements found in accepted source are for 50 percent of the children. The fact is that the children with cerebral palsy are usually closer to the lower percentiles, so we accepted data for 50 percent as appropriate for definition of the seat dimensions and adjustment ranges.

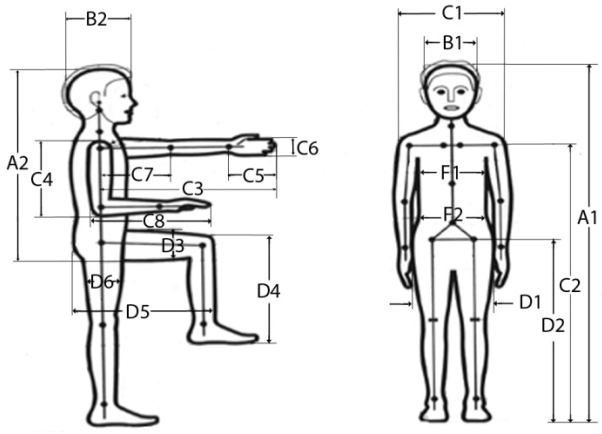



**Fig. 1.** Required measurements for seat design

According to accepted source [2] of anthropometric measurements, we have made a table of required measurements for seat design (Fig. 1). The first column in Table 1 shows the symbols for different measurements. The measurements for the children of 7 years of

age are in the second column and the measurements for 14 years old children are in the third column. Differences between the measurements are presented in the fourth column. The differences are actually necessary ranges of adjustability for all required measurements for the seat.

**Table 1.** Estimation of the ranges of adjustability

| Kind of measurement | Measure for 7 years old child in cm | Measure for 14 years old child in cm | Difference in cm |
|---|---|---|---|
| A1 | 1212 | 1594 | 382 |
| A2 | 657 | 823 | 166 |
| B1 | 140 | 148 | 8 |
| B2 | 181 | 191 | 10 |
| C1 | 291 | 383 | 92 |
| C2 | 966 | 1244 | 278 |
| C3 | 488 | 665 | 177 |
| C4 | 245 | 335 | 90 |
| C5 | 132 | 172 | 40 |
| C6 | 61 | 79 | 18 |
| C8 | 317 | 427 | 110 |
| C7 | 193 | 264 | 71 |
| D1 | 223 | 311 | 88 |
| D2 | 618 | 848 | 230 |
| D3 | 100 | 137 | 37 |
| D4 | 372 | 505 | 133 |
| D5 | 388 | 543 | 155 |
| D6 | 105 | 150 | 45 |
| F1 | 186 | 247 | 88 |
| F2 | 187 | 257 | 70 |

### 2.3. Ergonomic requirements

As a result of the anthropometric survey we decided to apply the principle of adjustability in order to design seat that could be adapted according to the needs of the patients. Due to the changes of the child's body during the childhood, there is a necessity for more space on the seat, and additional adjustments.

We set up ergonomic requirements for the wheelchair and the seat.

Ergonomic requirements for the wheelchair:

- possibility to change driving system:
  - for use in open space - manual system with big wheels or electrical one;
  - for use at home – system with small wheels with appearance like home furniture;
- possibility for having storage space;
- good suspension system;
- adjustable handles for companion's manipulation.

Ergonomic requirements for the seat:

- the angle between seat and backrest must be 900 (usual active position);
- the seat must have a possibility to change the angle of the backrest in order to provide rest position (900-1200);
- the seat must have a possibility to be transformed into support for standing (rotation of the seating surface into vertical position);
- the seat must have armrests for placing the arms in rest position;
- the seat must have additional supports from both sides of the chests for providing vertical position of the spine;
- the seat must have foot support for stabilization of the body;
- the seat must have additional support for legs for stabilization of the body in standing position;
- the seat must have additional support between the legs of the patient to prevent of spasms;
- the seat must have headrest with special shape as a support for obtaining proper position of the head;
- the seat must be soft in order to avoid wounds;
- dimensions of the seat must be appropriate for the child's dimensions.

Additional requirements:

- possibility for installing a small table for performing different activities: writing, drawing, having a meal, working on computer etc.;
- possibility for installing additional medical equipment.

## 3. DESIGN CONCEPT

In order to solve the problem of wheelchair design we applied two main design principles: principal of modularity [4] and principal of adjustability [5].

### 3.1 Concept of modular wheelchair

The principal of modularity [4] is applied to the main concept, where we propose the wheelchair to consist of two main parts: seat and driving structure. We propose three different driving structures: manual with big wheels for outside use, manual with small wheels for inside use and electrical one. The seat has to obtain maximum comfort for the patient. It is an independent part that could be placed on any of these structures and it could be also placed on the back seat in any vehicle.

Driving system for outdoor use could be manual or electrical (Fig. 2). Driving system for indoor use is usually manual (Fig. 3). The design of the whole wheelchair for indoor use should be adapted on the home ambience. This is especially important for the children from psychological viewpoint.

**Fig. 2.** Seat with driving system for outdoor use

**Fig. 3.** Seat with driving system for indoor use

### 3.2 Concept of adjustable seat

Both principals, principal of modularity and principal of adjustability, are applied to the concept of the seat. In order to follow the changes of children dimensions during their childhood, we propose design of modular seat with several adjustable parts: seat, backrest, headrest, armrests and footrests. All of these parts could be adjusted according to the child's dimensions. The other advantage of the applied modularity is possibility to replace parts because of changes in medical treatment, damaging or because of the need for a better one.

Another advantage of the modular adjustable seat is its ability to transform into a device for the support of the standing disabled child (Fig. 4). The best fit of the seat for performing of this function is in combination with the driving system for indoors use, because it is usually performed in home environment.

**Fig. 4.** Transformation of the seat into standing support

**Fig. 5.** Seat with additional equipment – table for playing, writing

The seating surface must be with maximum width and maximum depth. In order to follow the dimensions of smaller patients the width could be adjusted with armrests position and the depth could be adjusted with backrest position.

Seating surface could be rotated around the axis in the back edge in order to achieve vertical position for obtaining standing position of the patient.

Foot rest must be adjustable along the distance between the set surface and lower foot surface and also the grips for legs.

Armrests must be adjustable in vertical direction and also in horizontal in order to adjust the width of the seat. Headrest must be adjustable in vertical direction.

### 3.3 Additional equipment

The principal of modularity [4] and adjustability [5] is also applied to the possibility for obtaining extra accessories for performing different tasks: having a meal, writing, drawing, playing, working on computer, standing etc (Figs. 5, 6, 7). Sometimes there is a need to put additional medical accessories for obtaining stable posture. The advantage is possibility for the users to supply them according to their needs.

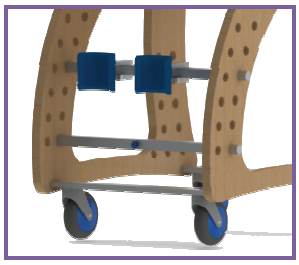


**Fig. 6.** Additional adjustable equipment for leg support

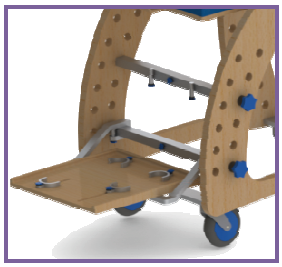


**Fig. 7.** Additional adjustable equipment for foot support

## 4. WHEELCHAIR COMFORT EVALUATION

At the end of design process it is necessary to make appropriate evaluation of the product. The best way to make evaluation is by means of a real model, prototype. But, there are many software products with virtual mannequins, used mostly in automotive design. We used software module Human Builder of CATIA to make an appropriate analysis.

In order to provide for a proper analysis we undertake several steps: selection of appropriate mannequins for the patients and companion person, selection of body positions for evaluation, performing of measurements and summary of obtained results.

### 4.1 Selection of appropriate mannequin

Human Builder software creates virtual mannequins according to the incorporated database of anthropometric measurements of people of different nationalities and gender, organized in tables of percentiles. But, there are no data for children and no special virtual mannequins for children. In order to select appropriate mannequins to represent children

of different ages we had to make comparison between the known data for children and data from the database of Human Builder for different nationalities and gender.

We started with selection of two referent dimensions as known data for children: height of knee and distance between knee and hip. We took the referent data for further comparison from the available source [2] and made Table 2.

**Table 2.** Referent data for children of age 7 and 14 years

| Age | Height floor- knee in mm | Height knee-hip in mm |
|---|---|---|
| Child 7 years | 311 | 338 |
| Child 14 years | 425 | 463 |

We had to find the smallest woman to represent a child of 7 years and a bigger man or woman to represent a child of 14 years. According to the data of available nationalities for selection of virtual mannequins in Human Builder we decided to use data for Korean people as the smallest and French people as representing the Europeans. We had to extract the data for different genders and percentiles, and we had to put them in Table 3 in order to be available for comparison.

With comparison of the data between Table 2 and Table 3 we found that the best solution for selection of virtual mannequin for 7 years old child is a Korean woman of 5th percentile (Fig. 8). Also, the best solution for selection of virtual mannequin to represent 14 years old child is a Frenchman of $50^{th}$ percentile (Fig. 9).

**Table 3.** Data from the database of Human Builder for different nationalities, gender and percentiles

| Percentile | Gender | Nationality | Height of knee in mm | Height knee-hip in mm |
|---|---|---|---|---|
| 5th | Man | French | 355 | 450 |
| 5th | Woman | French | 315 | 405 |
| 50th | Man | French | 377 | 488 |
| 50th | Woman | French | 337 | 442 |
| 95th | Man | French | 398 | 527 |
| 95th | Woman | French | 360 | 477 |
| 5th | Man | Korea | 297 | 430 |
| 5th | Woman | Korea | 299 | 382 |
| 50th | Man | Korea | 316 | 459 |
| 50th | Woman | Korea | 317 | 414 |
| 95th | Man | Korea | 334 | 488 |
| 95th | Woman | Korea | 335 | 446 |

**Fig. 8.** Virtual mannequin of Korea woman, 5th percentile

**Fig. 9.** Virtual mannequin of French man, 50th percentile

In order to make evaluation of the hand comfort for the person who is pushing (driving) the wheelchair we use two virtual mannequins to represent the persons taking care about the patient. Because of the fact that the wheelchair is designed for the market in Europe, we use French woman of 5th percentile and French man of 95th percentile.

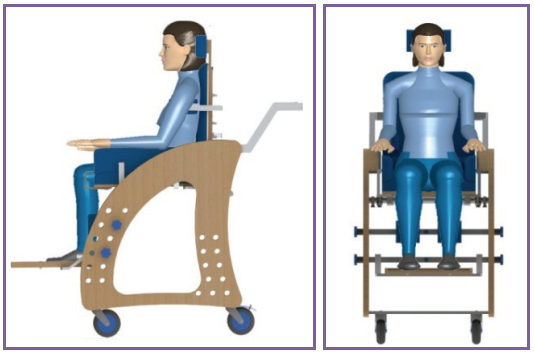
### 4.2 Selection of body positions for examination

The next step was to select body positions for evaluation. In accordance with the designed adjustable, modular wheelchair, seating and standing are the most important body positions for evaluation. But, for performing of everyday tasks, like playing games, working on computer, writing, drawing etc, the zones of convenient reach of the hands are also important. The important evaluation is also the hand comfort for the companion person who drives the wheelchair using the adjustable handles on the backrest of the wheelchair.

### 4.3 Virtual evaluation performing

In the third step virtual mannequins were designed and applied in the file of the wheelchair 3D model.

The first evaluation was performed to verify the seat comfort for 7 years old child. The 3D model of the wheelchair was adjusted for the user of age 7. The virtual mannequin representing 7 years old child was placed on the seat of a wheelchair adjusted in the position for seating (Figs.10,11). The same mannequin was placed on the wheelchair adjusted in the position for standing (Fig. 12).



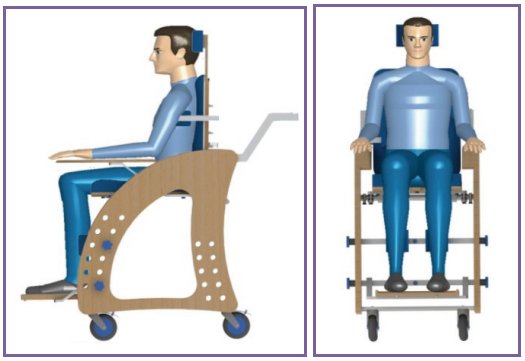
**Figs. 10, 11.** Evaluation of a wheelchair adjusted for seating of 7 years old child

**Fig. 12.** Evaluation of a wheelchair adjusted for standing of 7 years old child

The second evaluation was performed to verify the seat comfort for the child of age 14. The 3D model of the wheelchair was adjusted for the user of age 14. The virtual mannequin representing child of age 14 was placed on the seat of a wheelchair adjusted in the position for seating (Figs.13,14). The same mannequin was placed on the wheelchair adjusted in the position for standing (Fig.15).

The third evaluation was performed to verify the zones of convenient reach for the child of age 7 in seating position. The virtual mannequin representing child of age 7 was placed on the seat of a wheelchair with arms in rising position in order to ketch something around (Fig.16).

The same kind of evaluation was performed to verify the zones of convenient reach for the child of age 14 in seating position with arms in rising position in order to ketch something around (Fig.17).



**Figs. 13, 14.** Evaluation of a wheelchair adjusted for seating of child of age 14

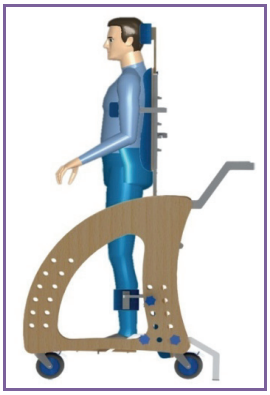


**Fig. 15.** Evaluation of a wheelchair adjusted for standing of child of age 14

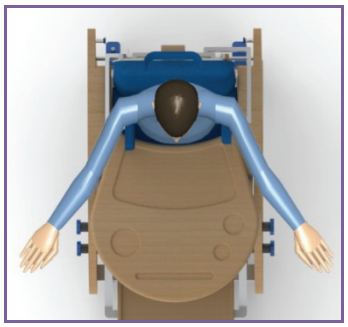


**Fig. 16.** Zones of convenient reach for child of age 7

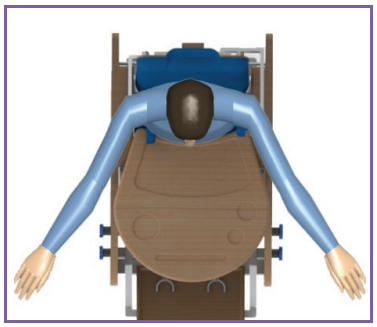


**Fig. 17.** Zones of convenient reach for child of age 14

The last evaluation was performed to verify the hand comfort for the companion person who drives the wheelchair using the adjustable handles on the backrest of the wheelchair. There were made two evaluations with two different virtual mannequins: Korea 5$^{th}$ percentile woman, as the smallest person who can drive the wheelchair (Fig.18) and French 95$^{th}$ percentile man as the biggest person who can drive the wheelchair (Fig. 19).

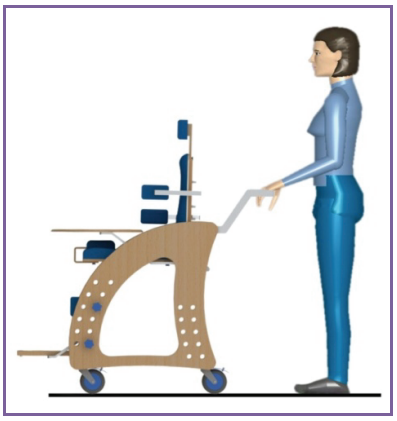


**Fig. 18.** Hand comfort for the smallest companion person driving the wheelchair

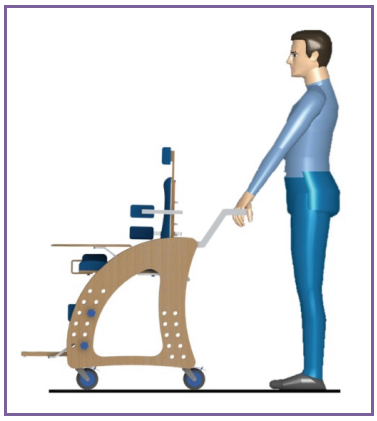


**Fig. 19.** Hand comfort for the biggest companion person driving the wheelchair

### 4.3 Summary of the results

The evaluations completed and shown in Figs. 10 - 19, the end conclusion is drawn. All of the evaluations show that the designed adjustable modular wheelchair obtains the necessary dimensional comfort for the children of ages between 7 and 14 in seating and standing positions. The zones of convenient reach are also acceptable for the children of ages between 7 and 14 for obtaining comfort for different everyday activities. The last evaluation also shows that the height of the adjustable handles for the companion person of different body size is also comfort enough in performing the action of driving the wheelchair.

## 5. CONCLUSION

The presented design of the adjustable modular wheelchair for children with cerebral palsy is only a small step to help people with disabilities. The principal of adjustability and modularity are always good decision for obtaining comfort for different persons. Also, for the patient's families this means an economic advantage, because the necessity for new wheelchair will be minimized.

The main advantage of this paper is not only to show the advantages of the designed wheelchair, but also the application of new tools in the design process. Contemporary software products for ergonomic evaluation using virtual mannequins are a very useful tool for the design process. They are used mostly in the automotive design, but they can be successfully used in the design of other products where the body size of the user is important.

But, evaluation on a real prototype is the most significant and valuable. Our next step is to make a real prototype of wheelchair and to make evaluation of a wheelchair comfort with real users.

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# PRIMENA VIRTUALNIH MANEKENA U PROCESU PROJEKTOVANJA I PROCENJIVANJA MODULARNIH INVALIDSKIH KOLICA

**Sofija Sidorenko, Jelena Micevska, Ile Mircheski**

*Pacijenti sa cerebralnom paralizom imaju potrebu za različitim invalidskim kolicima za unutrašnju i spoljašnju upotrebu. Na drugoj strani, deca sa cerebralnom paralizom odrastaju tako da nužnost većih kolica postaje ekonomski problem za njihove porodice. Da bismo zadovoljili njihove potrebe predlažemo model podešljivih modularnih invalidskih kolica. Primenom ergonomskih metoda i odgovarajućih antropometrijskih merenja dece ustanovili smo opsege podešljivih dimenzija za decu između 7 i 14 godina. Po tim dimenzijama načinjen je model podešljivog sedišta za stolicu. Uz primenu principa modularnosti sedište je projektovano da se može podešavati u nekoliko dimenzija a to su: visina sedišta, visina leđnog naslona, visina naslona za glavu, visina naslona za ruke i razdaljina kao i visina nožnog oslonca i razdaljina. Princip modularnosti je takođe primenjen na mogućnost smeštanja sedišta u različite vozne konstrukcije. Virtualni 3d model kolica se procenjivao uz pomoć virtualnih manekena u nekoliko različitih položaja: dimenziona udobnost u sedećem i stajaćem položaju, zone udobnog dohvata za sedećeg korisnika kao i udobnost ručnog dohvata za pratioca koji gura kolica.*

Ključne reči: *antropometrika, ergonomika, modularnost, virtualni maneken, invalidska kolica*