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ERGONOMICS APPLIED TO THE DESIGN OF VEHICLES FOR DISABLED

Marcelo Becker
Franco Giuseppe Dedini
UNICAMP, Faculty of Mechanical Engineering, Department of Mechanical Design
PO Box 6051 – 13083-970 – Campinas, SP, Brazil
E-mails: becker@fem.unicamp.br dedini@_

Abstract: *In this work the essential ergonomic aspects to the project of product to wheelchairs users will be approached, always looking for comfort, safety and costs. In the specific case of an ergonomic project of a vehicle for disabled, the following factors should be taken into account: user, vehicle and environment. It is extremely difficult to separate these factors, due to they are strongly coupled and dependent. For this reason, in this work, the physical (especially antropometric) and physiologic characteristics of the user, the comfort of the seat and types of the user's interface will be approached. A review about the main important problems and solutions in this area is showed.*

Keywords: *Ergonomics, Disabled People, Manual Propulsion, Powered Vehicles, Comfort.*

1. INTRODUCTION

The number of people who need mobility assistance is regularly increasing as a result of a longer life expectancy, automobile, work and sports accidents. The quality of live of wheelchair dependent individuals (WDI) is dependent upon a number of factors. Regardless of the nature of the pathology that forces one to the chair (for example: cerebral palsy, paraplegia, quadriplegia or head trauma), the user will necessarily meet difficulties related with quotidian tasks at home and outside of home. An Autonomous Vehicle for Disabled (AVD) is recommended for the cases where conventional electrical wheelchairs are not sufficient to compensate for mobility disabilities and an intelligent piloting assistance may improve driving comfort, and thus reduce physical and nervous exertion for WDI.

Many times the vehicle used to compensate the mobility disabilities causes several problems to the user like fatigue, stress, lesions and deformities due to bad posture etc. The main reason of these problems is that the vehicle has not a proper design to supply the user’s necessities. It is necessary to adapt the vehicle to the user looking for maximize the user comfort, safeness and minimize the costs. Every wheelchair must have certain elements of safety, construction, comfort and appearance. The basic needs in this kind of vehicle are (Becker & Dedini, 1999):

- Safety: The frame design should allow for normal activities within the seating platform and transfers in or out of the chair without tipping;

- Comfort: The seat and back of the wheelchair should be comfortable and provide support in good posture position for the trunk and extremities;
- Ease of Maneuvering: The size of wheels and casters, the system of ball bearings used, and the balance of the chair all contribute to the "rollability" of the wheelchair the ease of propelling the chair over rough or uneven surfaces;
- Durability: The design of the wheelchair, the materials and workmanship used in construction, and the assembly of the finished product should all be of good quality to allow continuous use of the wheelchair with a minimum of maintenance, and
- Attractiveness: The wheelchair is an extension of the individual, an integral part of the user's life and as such, should be as attractive as possible. The design of well-proportioned and simple lines, the finish of the metal parts, and the upholstery materials and color should all blend to provide an extension of the user's personality.

And, the essential aspects in this kind of vehicle are:

- Physical, physiological, psychological and social characteristics of the user;
- Type of interface user–machine, and
- Type of environment.

It is extremely difficult to separate these needs and aspects due to they are “strongly coupled and dependents”. One solution is to use ergonomic approach to design this kind of vehicles. But what is an ergonomic approach? Ergonomic approach means to use the anatomical, physiological and psychological knowledge to solve the problems of the relationship between man, environment, machine and work. This work focuses the basic idea necessaries to obtain a vehicle design that supplies the user’s necessities with an acceptable cost.

2. DIMENSIONS OF THE VEHICLE

The user’s anthropometric data are very important to obtain an ergonomic design of the vehicle. Through these data it is possible to verify the user’s limits to handle the controls and to improve the user’s posture on seat, avoiding muscular and spinal deformations and wounds like decubitus ulcers.

It is obvious that the ideal solution is to design each vehicle based on each user’s anthropometric data, but the cost of this solution is prohibitive. A more viable solution is to use some standard of anthropometric data. Unfortunately, there is no standard of anthropometric data about Brazilian population at this moment. Due to colonization and immigration, several ethnic groups (Europeans, Asians, Africans and Natives) form Brazilian population. These ethnic groups and the Brazilian social problems and regional differences become the population anthropometric data very variable.

Comparisons were made between German standard DIN 33402 and Brazilian workers in south and southeast regions of Brazil and showed data differences less than ± 5 % (Iida, 1990). It is possible to conclude that foreign standards like the German DIN can be used as initial approach to design the vehicle. In the vehicle tests phase the dimensions can be changed.

Also important is to design a vehicle with adaptable parts so, each user can adapt the vehicle to improve his comfort, and to allow the WDI access to corridors, bathrooms, cloakrooms, furniture etc.. The Brazilian Standard NBR 9050/1994 (ABNT, 1994) is quite complete in this area. The following Tables show the recommended position for some house gadgets (Tab. 1) and widths of corridors (Tab. 2):

Table 1 – Recommended position for house gadgets (ABNT, 1994)

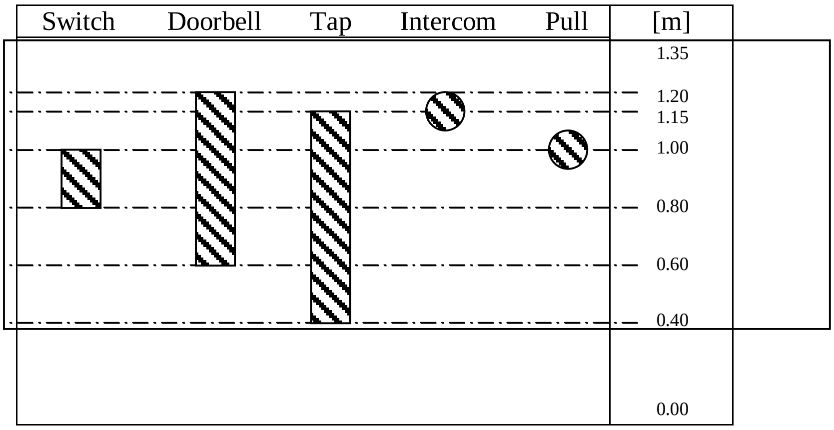


Table 2 – Recommended corridors widths (ABNT, 1994)

		Movement of 1 Wheelchair and 1 Person	Movement of 2 Wheelchairs
Corridor Width	[m]	Min. 1.20	Min. 1.50

It is quite obvious that the designer of any vehicle for WDI needs these informations to improve the user comfort and the project feasibility. But, the Brazilian standard NBR 9050/1994 (ABNT, 1994) and others “foreign” standards about accessibility and dimensions of conventional and electrical wheelchairs do only suggestions due to it is impossible to cover every kind of disability of WDI. Some cases need some particular solutions.

2.1 Seat

Special attention should be taken with the seat due to the WDI stay more than 16 hours per day in the sat down position (many times immobile for long periods) and the pressure in the buttock area causes reduction of the local sanguineous irrigation, skin necrosis and ulcers.

The pressure distribution in the region of the ischial tuberosities has a particular risk with respect to traumas (Bennett *et al.*, 1984). In this region (only 25 cm^2 of skin surface under these bones) stay 75 % of the body in sat down position total weight. Generally, ischial pressures should be inferior to 0.67 N/cm^2 and the coccix pressures, 0,27 N/cm^2 (Iida, 1990).

To reduce tissue damage in WDI, Gilsdorf *et al.* (1990) recommend: “having the user lean forward after a wheelchair back recline will greatly reduce undesired force” (shear force) and “wheelchair cushions with firm material under the thighs will facilitate reduction in ischial tuberosity pressure when the leg height is lowered as much as possible”.

Despite the diversity of wheelchair cushions currently in clinical use, pressure on bone prominences continues to be a major problem for WDI and the incidence of pressure ulcers remains high (Rosenthal *et al.*, 1996).

In future, commercial cushions must be anatomically and prosthetically designed to improve their performance. At this moment, the costs to do it are still height.

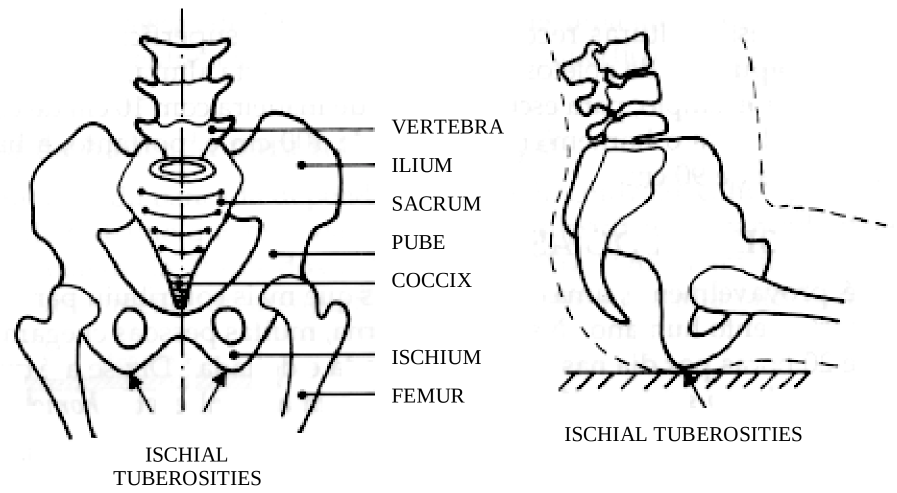
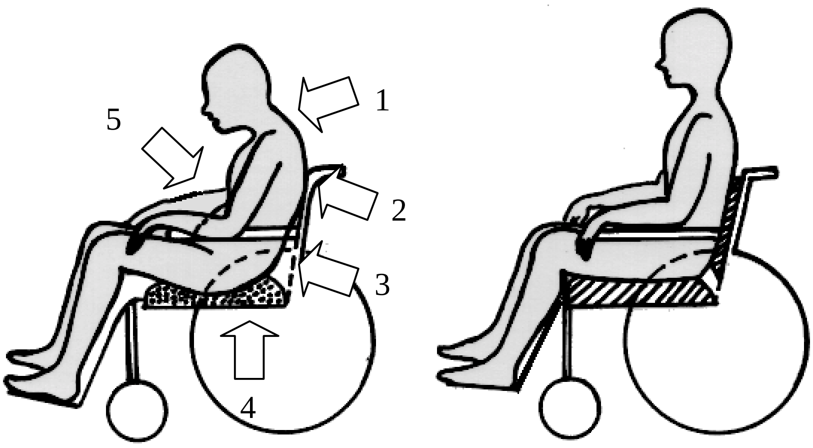


Figure 1 – Bones in the region of the ischial tuberosities.

2.2 Backrest, armrest and footplate

Others important parts of the vehicle are footplate, armrests and backrests. They together with the seat improve the pressure distribution on the ischial tuberosities and the body posture avoiding muscular and respiratory complications (most common complications). See Fig. 2-b: proper armrest, backrest and seat and the body posture of the WDI. The armrests also aid quotidian transferring tasks (vehicle to bed, to shower chair, to toilet etc.).



(a) (b)

Figure 2 – Effect of the proper wheelchair on body posture of the WDI.

Figure 2 - (a) shows how inadequate utilization of the seats and lumbar backrests by the WDI influences sacral setting postures, resulting in: (1) surcharge of the neck and superior backdorsum, (2) excessive scapular pressure, (3) hyperlengthning of lumbar extensors, (4) excessive sacral pressure and (5) little ventilation.

It is also desire that the armrests and backrests be angle and height adjustable and flip up vertically to adapt the vehicle to the anthropometric data of the WDI and for easy transfers.

Some cases, due to the WDI's level of disability, the transferring tasks will need other person assistance. In these cases, movable parts will aid and facilitate these tasks.

3. MANUAL PROPULSION

In the case of manual wheelchairs, wheelchair propulsion is a repetitive, cyclical movement that is the product of a user-machine interaction. Most user-machine systems, such as cycling or rowing, are often recreational and relatively short duration. The situation is entirely different for persons with disabilities who are dependent for their mobility on wheeled, human-powered machines. For children disabled in their lower extremities, the interaction with a machine is a lifelong experience (Bednarczyk & Sanderson, 1994).

The main factors that influence the propulsion of manual wheelchairs are:

- The level of motor disability (Dallmeijer *et al.*, 1994);
- The user's position on seat (Hughes *et al.*, 1992 and McLaurin & Brubaker, 1991);
- The user's age (Bednarczyk & Sanderson., 1994);
- Fatigue (Rodgers *et al.*, 1994) and,
- Behavior characteristics (McLaurin & Brubaker, 1991).

This item focuses how the ergonomics can be used to improve the efficiency of the wheelchair propulsion through the study of the user's position and the behavior characteristics. The user's position on the wheelchair (height of the seat and distance to wheels) has fundamental importance in hand-rim propulsion. The reason is that the position of the seat influences the propulsion efficiency due to the movement of the arms during the propulsion and return phases.

Studies indicate that although the conventional position of the seat is above the axis of the wheels, this is not the ideal position for maximum propulsion efficiency (McLaurin and Brubaker, 1991). The ideal position dependents on the shoulders position with relationship to the axis of the wheels and, also, on the dimensions of the segments those compose the arm. These parameters determine the geometry of the joint points and of the movements reach of the muscles used in the propulsion cycle.

Hughes *et al.* (1992) showed that the front seat positions, when compared to the back seat positions, have greater motion at the elbow and shoulder in frontal and transverse planes. Shoulder motion in the sagittal plane and stroke arc are greater for the back seat positions. Low seat positions have greater upper extremity motions than for high seat positions.

Again, the ideal solution is to study each individual and obtain an ergonomically ideal positioning for each case, avoiding lesions, deformations and stress associated to the propulsion movement of the muscles and, optimizing the propulsion cycle. The practical difficulty of this solution is the high costs involved in these studies. Even so, it is possible to join anthropometric and physiology data to obtain parameters recommended for users' bands, and use movable and adaptable parts in wheelchair construction to facilitate the seat correct positioning on the wheelchair.

There are four main factors, not dependent of the user, that influence in the necessary power for the propulsion of manual wheelchairs: the ground ruggedness, the wind, the ground inclination and the rolling resistance of the tires. The last is just a function of the design of the wheelchair but, can influence the performance of the system. For example, some types of tires are ideal for paved floors but, not for gram. The literature shows that high pressure pneumatic tires request ¼ of the necessary force to move when compared with solid rubber tires. The wheels alignment also influences in the rolling resistance, 1^o or 2^o can imply in an increment of 100% in the necessary force for the movement of the wheelchair (McLaurin & Brubaker, 1991).

The diameter of the wheels also has a significant effect in the rolling resistance. As general rule, it can be affirmed that the rolling resistance is inversely proportional to the diameter of the wheel. Looking on the rolling resistance, comfort and weight, pneumatic tires are preferable to solid rubber tires but, the development of synthetic materials is providing to solid rubber tires superior resistance and abrasion properties with rolling resistance values comparable to the pneumatic tires (McLaurin & Brubaker, 1991).

Ramps or inclines are commonly used to provide opportunities for WDI and to overcome differences between grade levels. But yet the limits of allowable grades have not been based upon stated scientific criteria. This reflected in the widely differing standards among various countries (maximum limit - France and Belgium: 5%, Poland: 12.5% and Brazil: 5 to 12.5%, see Tab. 3) (Cappozzo *et al.*, 1991). The Brazilian Standard NBR 9050/1994 (ABNT, 1994) indicates that the ramps can have different inclination limits:

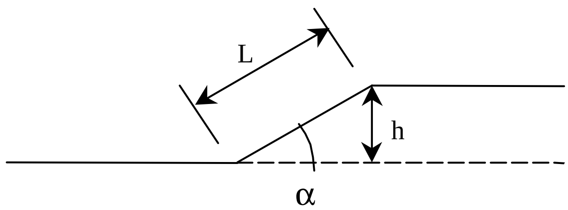


Figure 3 – Ramps nomenclature.

Table 3 – Design of Ramps (ABNT, 1994)

Ramp Grade (α) [%]	**Maximum Level Grade (h) [m]**	**Level Maximum Number**	**Ramp Maximum Length (L) [m]**
5.00	1.500	-	30.00
6.25	1.000 / 1.200	14 / 12	16.00 / 19.20
8.33	0.900	10	10.80
10.0	0.274 / 0.500 / 0.750	8 / 6 / 4	2.74 / 5.00 / 7.50
12.5	0.183	1	1.46

As commented in Item 2, the ergonomics must be used not only to improve the propulsion efficiency, but also to determine the vehicle dimension aim at the accessibility of the WDI to house gadgets and parts.

4. FROM POWERED WHEELCHAIR TO AVD

Due to the difficulties that some WDI had with the propulsion of manual wheelchairs, several years ago, some wheelchair factors introduce the powered wheelchair to improve the WDI independence. Through some kind of joystick, the user-machine interface was make. There are, in literature, several standards about electrical wheelchairs. The most used are the Americans standards ANSI/RESNA and ISO about manual and electrical wheelchairs.

The usefulness of powered wheelchair for WDI no longer needs to be demonstrated. However, it is still difficult or impossible to use for some people. In certain cases, a simple improvement of the standard joystick may be sufficient to compensate for the control difficulties. But, for WDI with severe motor or cognitive impairments (cerebral palsy, tetraplegia, head trauma etc.), improvements in the powered wheelchair control are not sufficient, and it is necessary to add a navigation aid, which could copy mobile robotic techniques (Bourhis & Pino, 1996).

Initially, on 80 decade, the microcomputers restricted the development of AVD due to its limitations of memory, performance of CPU, weight etc., that become unpractical its on-board use and real-time response (Madarasz *et al*., 1986). Then, like an AGV – Automated Guided Vehicle – used in the industrial field, an automated wheelchair guided by a ferrite maker lane on the floor was developed (Wakaumi & Nakamura, 1992). While this approach is used readily in factory automation problems, the use of guide tracks may de impractical and difficult to implement and maintain due to the variety of complex paths that are required for household or office navigation and the need for an easily reconfigured system. Many times, Latter, on beginning of 90 decade, the development of the microprocessors and sensors, allow the use of on-board systems with real time response and the development of wheelchairs that uses the AMR – Autonomous Mobile Robot – principles of path planing and obstacle avoidance.

Today, there are several researches working on this kind of vehicle, we can refer Yoder *et al*. (1996), Bourhis & Pino (1996) and Katevas *et al*. (1997). There are also projects of wheelchairs with legs that are capable of traversing uneven terrain and circumventing obstacles (Wellman *et al*., 1995) and wheelchair with a prosthetic arm to aid the WDI in quotidian tasks, like eat, drink etc., improving the WDI's quality of life (Wang, 1997). The future seek design of vehicles with emphasis in:

- The vehicle image (attractiveness): to avoid the association with user and disability or inability, very frequent fact in conventional wheelchairs and improving the user's psychological aspect and self-image, giving to the WDI a healthy and attractive corporal image;
- Interface: to adapt the types of interface user - vehicle to each type of the user's deficiency;
- Maximum comfort, maneuvering, durability, safety, and
- Minimum fatigue and stress: to prevent deformities and lesions due to bad posture and, the user's safety.

To attain these objectives, the designer will need to use more and more the Ergonomics. At this moment, there is no special standard for AVD; the recommendation is to use the standards for electrical wheelchairs as a reference parameter.

5. CONTROL AND INTERFACE SYSTEMS

In the case of powered wheelchairs and AVD, conversation and task sharing have to be established between vehicle and WDI, which, moreover, offers psychological advantages – to reduce the WDI's feeling of dependence. But it is essential that the vehicle does not degenerate to be used simply to transport the WDI (a "body") from one point to another. Too much autonomy for the AVD could reduce the WDI's feeling of autonomy. To avoid this kind of problem, the use of 3 working modes for the controller is advisable (Bourhis & Pino, 1996): automatic mode, assisted mode and manual mode. The objective is to have a control system which would best share tasks between WDI and the AVD according to the extent to which the WDI is impaired and to the complexity of the environment.

In the automatic mode, the AVD carries out autonomous trajectories, with the WDI only supervising the movement. The assisted mode allows access to behavioral primitives like wall following or obstacle avoiding. And, in the manual mode, the classical control of a powered wheelchair is used, with a possible adaptation of the man-machine interface.

This implies 2 restrictions in the AVD design: the controller of the AVD must be modular to adapt to a great variety of situations and levels of disability and, the system must accept information coming from all types of man-machine interface sensors, whether they are on-off switches, proportional or complex. Nowadays there are several commercial interface systems that enable the WDI to operate the vehicle, a computer or control some house parts (TVs, radios, windows etc.). The most common alternative interfaces are:

- Joystick;
- Finger sensors;
- Sip and puff sensors;
- Head sensors, and
- Chin sensors.

The last 3 sensors are recommend for WDI without motor coordination of superior members. In future, the use of speech recognition as an interface system will improve the comfort and reduce the stress of the WDI.

6. CONCLUSIONS

At present there are many researches working in autonomous assistance for WDI but few researches give importance to the ergonomic aspects of the projects. The most important idea is that the vehicle is not transporting the WDI from one point to another. It is necessary to verify the comfort, safeness and mobility independence of the users and not only the controller and the costs of the vehicle. The user comfort must be the target of the designer and the technology must be used to get it. Anthropometric data of the users are a very important parameter to design products for WDI. Ergonomics aspects must be taken in consider. The future seek design of vehicles with emphasis in: vehicle image (attractiveness); maximum comfort, maneuvering, durability, safety; minimum fatigue and stress; the use of speech recognition as an interface system and new technologies in control of autonomous vehicles (fuzzy logic, neural networks, adaptive control etc.) to improve the comfort and safeness of the WDI. To attain these objectives, the designer will need to use more and more the Ergonomics.

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