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PRODUCT STUDY AND DESIGN FOR THE ERGONOMIC FEASIBILITY OF A TILTING WHEELCHAIR

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Abstract

It can be understood that people with limitations requiring the use of a wheelchair besides having mobility restrictions and health problems as a consequence of staying on a sitting position for extended periods of time, also depend on the daily help of caregivers for various activities. The objective of this study was to evaluate the ergonomic and economic viability of a tilt system wheelchair project. To achieve it, the optimal ergonomical and physiological inclinations of the seat and back support were mapped, as well as required changes that resulted in accessibility, mobility, health and safety benefits. Through theoretical research and interviews and conversations with wheelchair users, doctors and professionals in the area, it was possible to obtain theoretical and practical knowledge for the best possible application of the idea. After deep immersion in the problem and analysis of the needs and requirements of the targeted niche, a wheelchair containing the suggested improvements was designed, aiming to meet the needs of the users according to their clinical stage. The ergonomics of the designed product have been evaluated through angled seat and backrest combinations analysis, which have proven a better distribution of wheelchair blood pressure, reducing illnesses from excessive sitting. In conclusion, the work had its objective achieved, because when compared to a conventional wheelchair, postural improvements and risk reduction in the removal of the patient by the caregiver were evidenced.

Keywords: Wheelchair; Ergonomic; Caregiver; Tilts; Accessibility.

1. INTRODUCTION

According to data from the IBGE Demographic Census, more than 45 million (23.9% of the total population) of Brazilians declare themselves to have some visual, hearing, mental or motor disability, with motor disability equivalent to approximately 7% of the inhabitants (about 30% of the disabled) in the country (IBGE, 2010; IBGE EDUCA, [n.d.]).

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To overcome a motor disability (temporary or permanent), it may be necessary to use a mobility chair, which should provide the best ergonomic and physiological comfort for the individual's health, thus reducing the diseases derived from their initial condition.

The removal of the patient by the caregiver should also be analyzed, aiming to reduce risks in all activities involved in a wheelchair.

Ergonomic methodologies such as RULA and REBA can be used to analyze the ergonomics of wheelchair users and caregivers because they analyze, respectively, the patient's posture in the equipment and the risk involved in the activity of removing the patient by the caregiver, justifying the performance of this work.

The Wheelchair with tilt system does not define the ergonomically ideal inclinations for the patient, only the sitting position and inclinations defined by the patient or caregiver himself. Incorrect inclinations can lead to health complications, resulting for example from lack of blood circulation, muscle atrophy or postural problems due to the choice of a bad position.

Thus, the present study aimed to propose an intervention and perform an ergonomic analysis in a wheelchair with a tilting system. The project aims to ensure that the product is able to provide the necessary ergonomics both for individuals with restricted movement or diseases that limit their movement and for their respective caregivers.

2. Methodology

To define the questions that were presented in the questionnaire, the methodology for the elaboration of the questionnaire and the behavioral techniques proposed by Iida and Buarque (2016) were used. This methodology includes: (1) planning: what objectives, deadlines and reliability; (2) definition of the sampling: evaluated considering the target audience, sample size and sampling procedure; (3) construction of the questionnaire: list of questions, ordering, layout, processing of answers.

The objective of the planning was to collect data from people who use wheelchairs or at some point in their lives used them or health professionals (physiotherapists and doctors), providing for our ergonomic study what was really necessary to implement improvement in order to meet the needs and desires of the market. In order to receive answers with greater reliability, they were considered anonymous, preserving the identity of the individual.

The definition of the sample was extremely filtered, with the help of physician Silvio Labate Rodrigues and medical students from UNIMES (Santos, SP) in sharing the questionnaire with patients and their respective caregivers in clinics and hospitals. Thus, 43 people responded to the questionnaire until June ten, two thousand and nineteen.

Putting into practice a scale used to measure attitudes and know the degree of compatibility based on the *Likert model*, the construction of the questionnaire was strategically ordered in the following sequence:

a) Age

b) Sex

c) Are you a user, doctor or caregiver?

d) What type of limitation do you or your patient have?

e) What is the degree of your limitation or the limitation of your patient?

f) Why do you or your patient use a wheelchair?

g) How often is the equipment used?

h) How was this chair purchased?

i) What is the weight of the wheelchair currently used?

j) How do you rate wheelchair functionality and comfort?

k) How do you rate wheelchair ergonomics and safety?

l) How do you classify the issue of accessibility of support equipment (tables, supports, showers, etc.) of the wheelchair?

m) Would defining more than one ergonomically optimal position be important for your comfort or the comfort of your patient?

n) Do you consider a wheelchair with a tilt system a good product?

o) Are people with limitations treated equally compared to people without limitations?

p) What are the main barriers encountered by a wheelchair user?

q) What suggestions for improvement do you think are relevant to make your wheelchair ideal?

DATA COLLECTION

Some of the methods presented by Iida and Buarque (2016) for collecting experimental data were applied in this study. Direct and informal observations were carried out, seeking to qualitatively understand the effort made by wheelchair users and their respective caregivers. In addition, a focus group and informal interviews were practiced at the "Hospital Fair 2019", with the objective of understanding the current scenario of the market for wheelchairs and other physiotherapeutic utensils that help the patient, gathering qualitative information.

In the qualitative evaluations, it was obtained through an interview with the physiotherapist Francisco De Paula, that patients often do not care about the ideal positions (ergonomically feasible) but about their momentary comfort, that is, often the complications caused by excessive permanence in the wheelchair are the result of a misuse of the patient himself.

Another aspect raised in the conversation was that most caregivers, because they make repetitive movements and are with the patient 24 hours a day, end up having complications mainly in the lumbar when handling/transporting the patient from the wheelchair to a bed, table, bathroom, among others.

ERGONOMIC ANALYSIS

Ergonomic work analysis aims to evaluate, understand and correct a real work situation through ergonomic knowledge, branching into demand analysis, task analysis, activity analysis, diagnosis and recommendations (IIDA, 2005). According to the Brazilian legislation in Regulatory Standard 17 (BRASIL, 1978), in order to assess the adaptation of working conditions to the psychological and physiological characteristics of workers, it is up to the employer to carry out an ergonomic analysis of the work, which must address, at least, the working conditions. Working conditions include aspects related to the lifting, transport and unloading of materials, furniture, equipment, the environmental conditions of the workplace and the organization of work itself (COUTO, 1996).

The present work used ergonomic tools to simulate the wheelchair user, unlike a workstation, but, due to the excessive permanence in the equipment, its activities could be interpreted in a similar way to all the tools used in the project (Dassault-Ergonomics and Ergolandia – RULA and REBA Methods).

With a target audience of practically 50% of the elderly, it was taken into account that, from the age of 50, there is a decrease due to aging in static anthropometry, in which 3cm are lost until the age of 80, resulting in a posture that is increasingly far from ideal and facilitating further complications. The ergonomic analysis that the work proposes is precisely to avoid these problems resulting from excessive permanence in the wheelchair.

As a consequence of the ergonomic analysis in the object of study of the present study, 17 possible adaptations in the wheelchair were mapped, divided into 4 distinct fronts (Chart 1):

Chart 1 - Mapping of improvements

Accessibility and mobility	Safety	Health	Aesthetics
• Accessory Holder • Cup Holder • Umbrella Adapter • "Multipurpose" Table • Folding chair • Foldable arm support for easy patient removal/insertion • Possibility to migrate the Right or left side "controls"	• Increased distance between rim and wheels Brake system (for patient and caregiver) • Fall arrest system located on the wheels • Seat Belt (Trunk/Legs/Arms)	• Pillows with Eggshell mattress • Leg massager • Oxygen Tank Adapter • Adapter/Support for serum/blood hook etc.	• Block Single/Single Frame (Seat/Backrest/Legs) • Customization of Hubcaps and other accessories •

Source: Authors

Formulation of the Diagnosis

The diagnosis seeks to find the reason that causes the problem mentioned in the analysis of demand, task and activity (ABRAHÃO et al., 2009). In view of the answers collected, it was possible to perceive that the complaints by the caregivers deal exactly with fatigue and injuries to the lower back due to the constant movements and the excessive working hours. From the point of view of users, the biggest complaint is due to the excessive period in the wheelchair, resulting in pressure ulcers and thrombosis, which can in the medium and long term bring new complications to them, directly reducing their quality of life and life expectancy. In addition to the presentation of the collected data, the *Ergonomics* Software was used to formulate the diagnosis through the simulation of the activities studied at the workplace.

Ergonomic Recommendations

The recommendations present in the study are associated with what should be done to solve the diagnosed problem, presenting very detailed steps to solve the problem (IIDA; BUARQUE, 2016). It is necessary to remodel the wheelchair, contemplating all the variables that interfere with the movement, mobility and accessibility of the patient and the caregiver. In other words, these are recommendations for the evaluation of micro and macro ergonomics with the objective of presenting viable solutions to the evaluated case study.

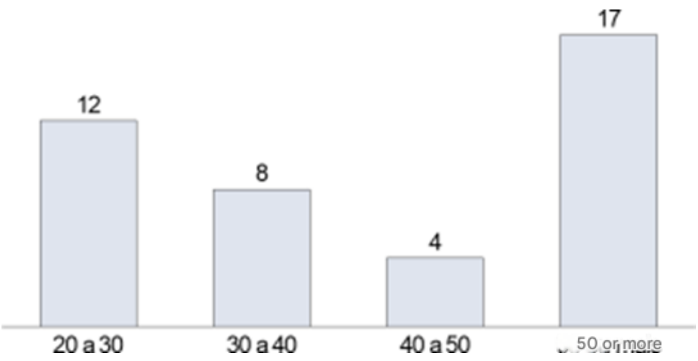
3. Results and Discussions

The survey was carried out with the objective of understanding the profile of individuals who use wheelchairs, seeking to understand their needs, reason for use, attributes and limitations of the equipment, with the final aim of understanding the ergonomics of the equipment and possible improvements to be implemented.

The analysis was divided into six blocks, the first being a census, to understand the characteristics of the respondents in the sample, which had 41 responses.

Figure 1 shows the distribution of responses by age group. Considering the age group, it is possible to see that the highest concentration is in the 50 and over age group, with emphasis also on people aged 20 to 30 years.

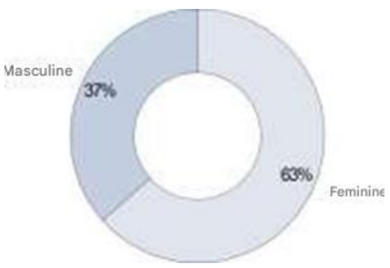
Figure 1 - Age group



Source: Authors

The gender distribution, in turn, points out that females represent 63% of the respondents, while males indicate a lower percentage (37%). It can be noted that the sample distribution is segmented in a similar way between users (49%) and caregivers (41%) when comparing the respondent's profile. Physicians, in turn, represented 10% of the responses (4 responses), as shown in Figure 2 and Figure 3, respectively.

Figure 2 - Sex



Source: Authors

Figure 3 - Respondent

Source: Authors

The second block of answers aims to understand the type and degree of limitation, as well as the reason for the use of the equipment by the user or patient cared for by the caregiver.

Physical limitation covers almost 50% of the respondents, being the main focus of analysis and implementation of solutions, followed by multiple disability, which affects 31.71% of the respondents. Motor and mental limitations have a representativeness of 14.63% and 4.88%, respectively. The answers can be seen in Figure 4. Figure 5, which evaluates the degree of limitation, shows that partial limitation represents the majority of the sample, with 34 responses. Seven interviewees had total limitation or cared for people with this degree of limitation.

Figure 4 - Type of limitation

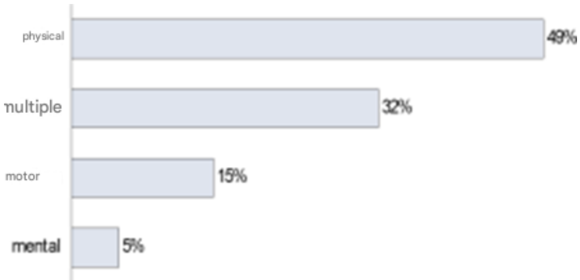


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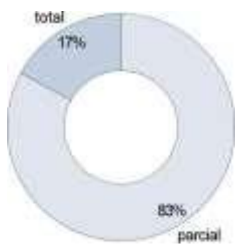
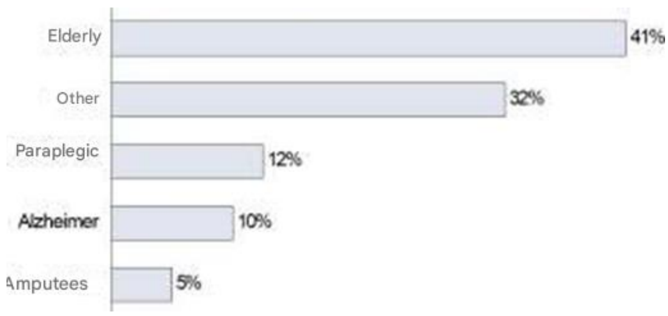
Figure 5 - Degree of limitation



Source: Authors

Evaluating the reason for using wheelchairs, it is notable that age-related limitations represent the main reason for using wheelchairs, representing 41.46% of the statistical group (Figure 6). Other diseases also have high relevance, with 13 answers among the 41 interviewees and the other categories added together have 11 answers (26.83%).

Figure 6 - Reason for use

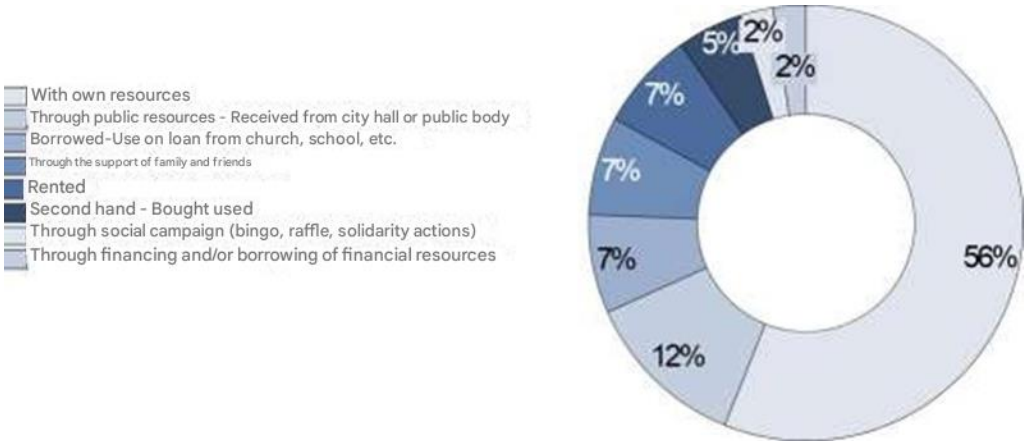


Source: Authors

The third block aims to analyze the generalities of the wheelchair for the respondents, with the objective of understanding the general functionalities of the equipment and mapping its respective purchase process and frequency of use.

From the analysis of Figure 7, it is possible to see that more than half of the sample acquired the wheelchair with their own resources (56.10%). The free receipt through donations from a public agency also has a large representation (12.20%), while the other options (Rent, Family and friends, social campaign, loan or financing) add up to 31.7%.

Figure 7 - How to buy



Source: Authors

The frequency of use shows that among the 41 interviewees, 39% (16 people) answered that they are either elderly people with low mobility or take care of the elderly. Continuous use and use only for rapid transportation present 12.10% of the responses, with 5 people each (Figure 8).

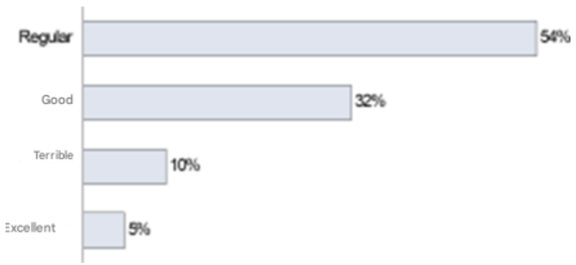
Figure 8 - Frequency of use

Source: Authors

In terms of the functionality of the locomotion chair, Figure 9 shows that, adding the regular and very poor categories, 63.42% of the interviewees admit that the equipment has some problem. It is also worth mentioning that less than 5% rate their chair as excellent.

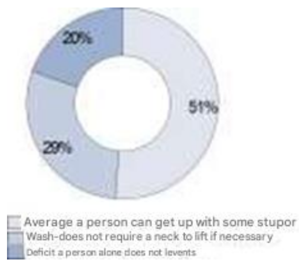
Figure 10 shows that weight, in turn, does not represent the main bottleneck in the evaluation of the equipment, since 29.27% consider it light and 51.22% understand that a person can lift the wheelchair with some effort.

Figure 9 - Equipment functionality



Source: Authors

Figure 10 - Equipment weight

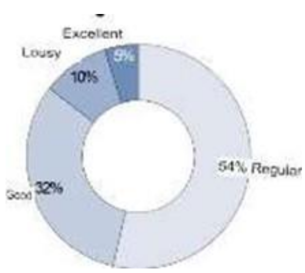


Source: Authors

The fourth block aims to understand the ergonomics of the product, aiming to map the accessibility and ergonomic quality of the product, in addition to understanding the importance of implementing a system of ideal inclinations.

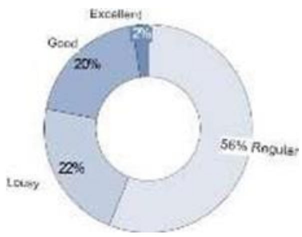
Figure 11 shows that, after adding the Regular (53.66%) and Very Poor (12.20%) classifications, it is notable that for most of the sample, the ergonomics of the wheelchair need improvement. When we analyze the accessibility of the support equipment for wheelchair users, present in Figure 12, 21.95% classify them as very bad and 56.10% as regular, representing, therefore, one of the main bottlenecks of the product and, consequently, a focus of action in this work. For both criteria, only 2.44% consider the locomotion chair Excellent.

Figure 11 - Ergonomics of the current wheelchair



Source: Authors

Figure 12 - Accessibility of support equipment



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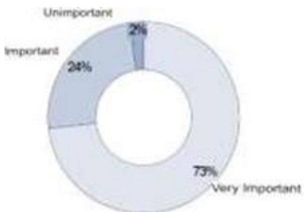
As for the implementation of a system of inclinations and the definition of ideal positions, it can be seen that the theme of inclination represents a great factor of attention and implementation of improvements for a wheelchair user. As shown in Figure 13, only 2.44% of the sample does not consider the tilting system in a wheelchair important, while 73.17% consider the attribute very important. In view of the definition of ergonomically ideal positions, 90.24% of the people interviewed consider it important to define more than one ergonomically ideal position, understanding that this system can bring benefits (Figure 14).

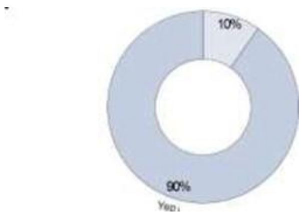
Figure 13 - Importance of the slope system.



Source: Authors

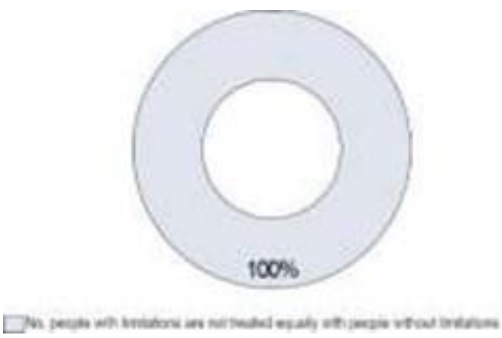
Figure 14 - Relevance of a slope system

Source: Authors



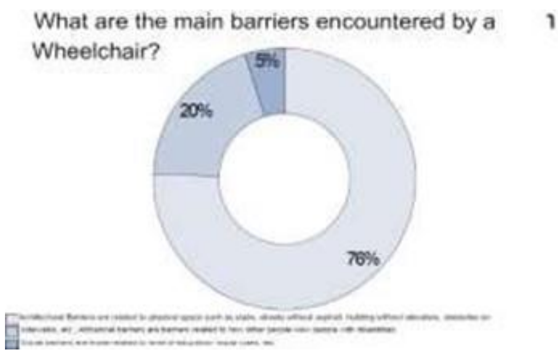
The fifth block of answers seeks to analyze the social integration of wheelchair users in society. Figure 15 shows that 100% of the sample understands that people with some type of limitation are not treated in the same way as people without limitations, while Figure 16 shows that, in the case of wheelchair users, 31 respondents (75.61%) see architectural barriers as the main problem to be solved.

Figure 15 - Treatment of wheelchair users



Source: Authors

Figure 16 - Main barriers encountered



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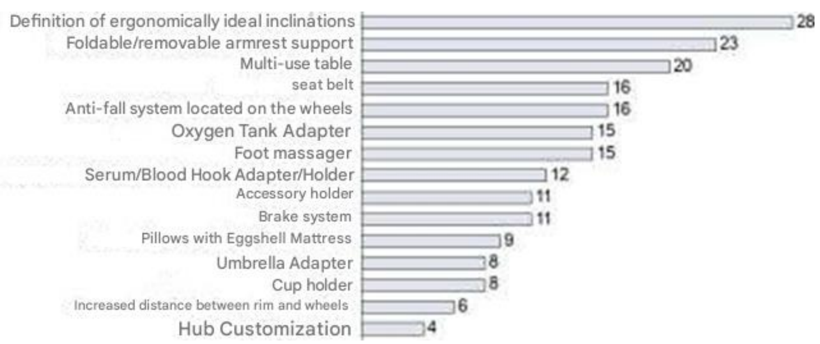
The sixth and last block of answers seeks to understand what are the most relevant improvements in terms of accessibility and functionality so that the wheelchair meets the needs of the wheelchair user and their respective caregiver. The analysis of the answers in Figure 17 showed 16 possible improvements to be implemented, with the main highlights being the definition of ideal inclinations via remote control, multipurpose table, folding or removable arm support, seat belt and fall arrest system.

Figure 17 - Survey Survey: Necessary improvements



Source: Authors

After immersion and analysis performed through the questionnaire answers, the ergonomics of the conventional wheelchair and the impact of removing the armrest to facilitate the transport of the patient by the caregiver were verified.

CONVENTIONAL WHEELCHAIR REVIEW

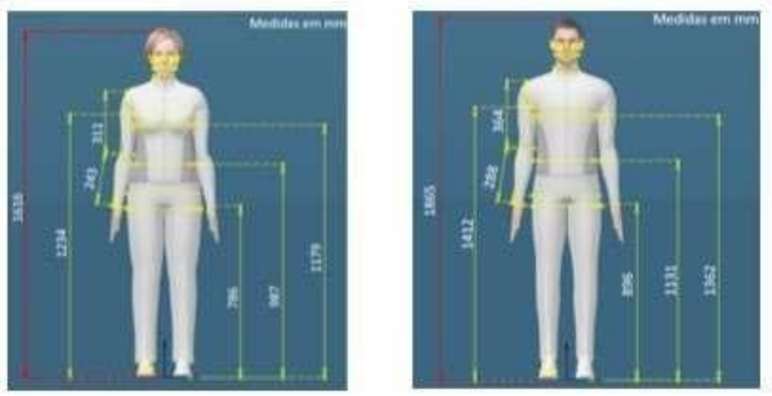
The wheelchair model described below in Figure 18 (conventional wheelchair according to ABNT standards) was analyzed by the *Ergonomics* software from *CATIA*, using the RULA methodology as a reference.

Figure 18 - Conventional wheelchair

Source: Authors

Two types of mannequins were tested to elucidate differences in height and weight among the general population. For the purpose of parameterizing the study, we chose a female and a male mannequin. Its dimensions are shown in Figure 19.

Figure 19 - Dimensions of the mannequins



Source: Authors

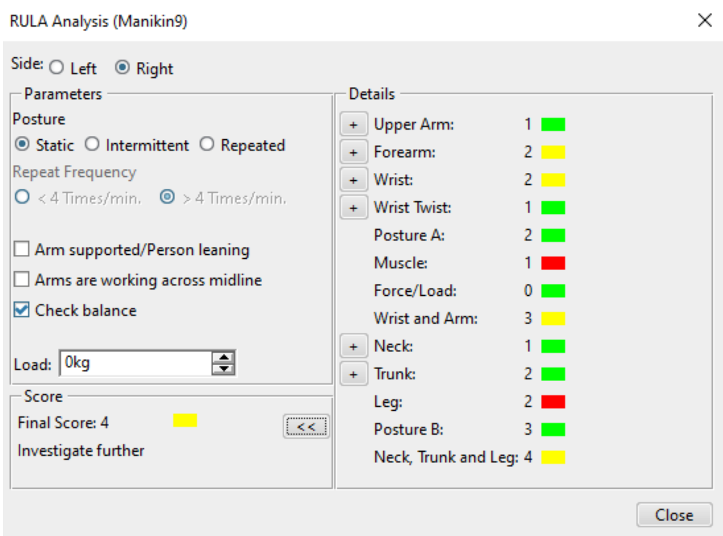
First, the analysis was performed with the positioning of the female mannequin (Figure 20) in the equipment.

Figure 20 - Positioning of the manikin

Source: Authors

We can observe that, as a result of its height, the mannequin is unable to allocate its legs and feet correctly, as it does not reach the supports intended for the feet. When analyzing the position of the arms, the distance between the armrests of the wheelchair and the ideal arm allocation is clear, which also leads to ergonomic losses in posture of the mannequin. The results obtained by applying the RULA methodology to the mannequin are shown in Figure 21.

Figure 21 - Result - RULA methodology for the conventional chair



Source: Authors

The analysis is done under the condition that the dummy is static in position. The indications that demonstrate the green color explain that the positioning of the upper arm, twisting of the wrist, neck and trunk. The three members analyzed separately are at an ergonomically acceptable level according to the RULA methodology. The yellow indexes, apparent on the forearm and wrist separately, adjunct of the entire arm combined with the wrist, demonstrate that, due to the lack of correct support of the manikin, it resulted in scores of 2 and 3, respectively. Finally, the combined analysis of the legs, trunk and neck announces the poor adaptability of the chair to the body of the female mannequin, resulting in unnecessary efforts and leading to the result of the entire analysis resulting in a level 4, where the RULA methodology that "changes may be necessary".

Next, the wheelchair with the male mannequin was analyzed, as shown in Figure 22.

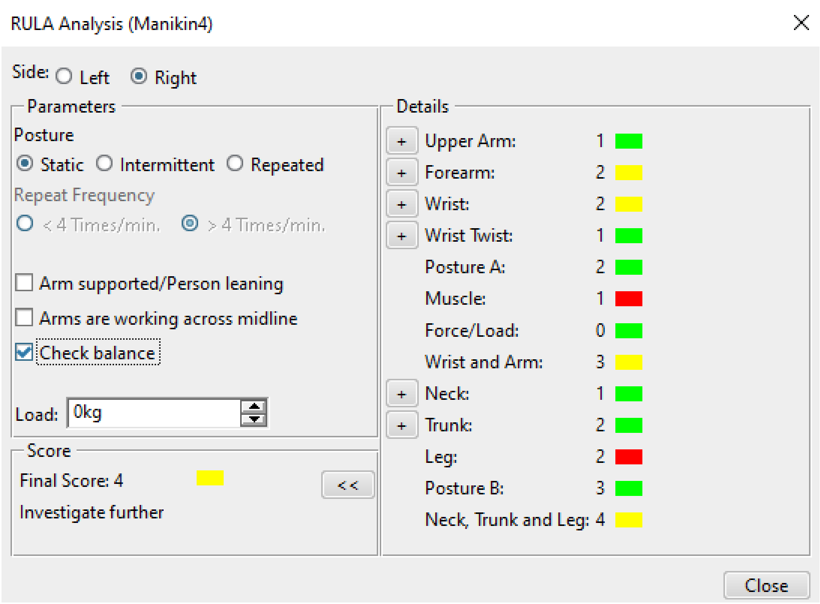
Figure 22 - Positioning of the manikin

Source: Authors

It can be observed that, due to its height, the mannequin is also prevented from accommodating the elbows and the entire extension of the arm (due to the lack of adjustment in the height of the armrests for different types of users). Their legs are accommodated in the foot support, but only with a certain angle of the legs, with the postural consequence of the non-optimal allocation of the legs.

Ideal for buttock support and leg length. The results obtained by applying the RULA methodology to the mannequin are shown in Figure 23.

Figure 23 - Result - RULA methodology for the conventional chair



Source: Authors

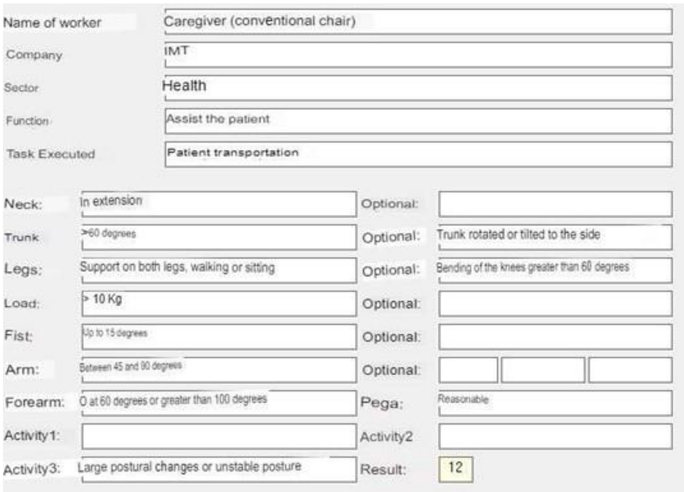
The results are very close to those found by the mannequin of different height and sex, and are also classified by the RULA methodology as grade 4, which has as a consequent intervention the realization of observations and the possibility of changes.

REMOVAL OF THE PATIENT BY THE CAREGIVER

In order to improve ergonomics in the process of removing the patient by their respective caregiver, it was suggested to remove the armrest. To verify the effectiveness of the action, the REBA methodology was applied, using the *ergolandia* software, indicating the results of Figure 24 and Figure 25.

1 - Caregiver diagnosis in a conventional wheelchair:

Figure 24 - REBA: Result for the wheelchair with the armrest



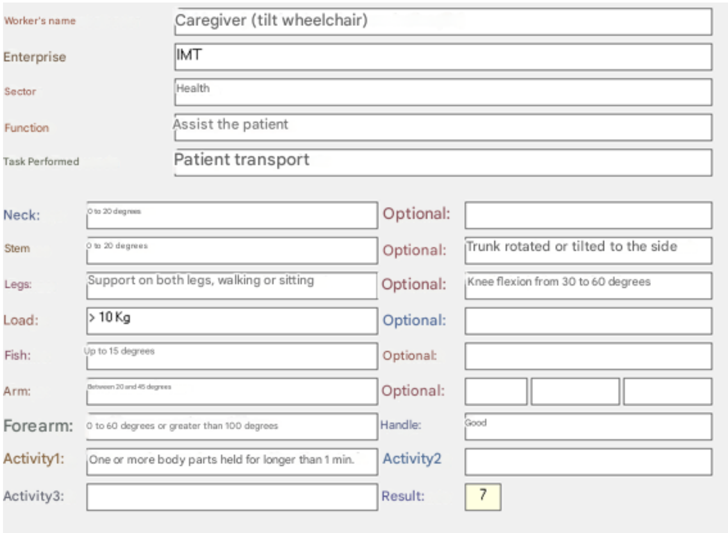
Name of worker	Caregiver (conventional chair)
Company	IMT
Sector	Health
Function	Assist the patient
Task Executed	Patient transportation

Neck:	In extension	Optional:	
Trunk	>60 degrees	Optional:	Trunk rotated or tilted to the side
Legs:	Support on both legs, walking or sitting	Optional:	Bending of the knees greater than 60 degrees
Load:	> 10 Kg	Optional:	
Fist:	Up to 15 degrees	Optional:	
Arm:	Between 45 and 90 degrees	Optional:	
Forearm:	0 at 60 degrees or greater than 100 degrees	Pega:	Reasonable
Activity1:		Activity2	
Activity3:	Large postural changes or unstable posture	Result:	12

Source: Authors

2 - Caregiver diagnosis in a tilting wheelchair with removable armrest:

Figure 25 - Result - REBA Methodology: Result without armrests



Worker's name	Caregiver (tilt wheelchair)		
Enterprise	IMT		
Sector	Health		
Function	Assist the patient		
Task Performed	Patient transport		
Neck:	0 to 20 degrees	Optional:	
Stem	0 to 20 degrees	Optional:	Trunk rotated or tilted to the side
Legs:	Support on both legs, walking or sitting	Optional:	Knee flexion from 30 to 60 degrees
Load:	> 10 Kg	Optional:	
Fish:	Up to 15 degrees	Optional:	
Arm:	Between 20 and 45 degrees	Optional:	
Forearm:	0 to 60 degrees or greater than 100 degrees	Handle:	Good
Activity1:	One or more body parts held for longer than 1 min.	Activity2	
Activity3:		Result:	7

Source: The authors, 2019

From the analysis of the REBA methodology, it is possible to observe a significant improvement in the process after the removal of the armrest. Initially, the result indicated a score of 12, resulting in immediate intervention and very high risk. After the proposal to remove the armrest, the process became medium risk, still requiring intervention, but to a lesser degree of intensity.

PRODUCT DEVELOPMENT

In view of the ergonomic benefit resulting from the removal of the armrest and the improvements in accessibility and functionality mapped from the questionnaire, a new product was developed in the *SolidWorks* software, with the objective of meeting all the proposed suggestions and having an inclination system that defines the ergonomically and physiologically ideal positions, using the *backrest and seat tilt system for its viability*.

The designed system has the systematic dynamics of changing the orientation of someone sitting in a wheelchair, but keeping the hip, knee and ankle angles the same. The main purpose of the system is to redistribute pressures or loads on the body, particularly on the ischial tuberosities and tailbone or the distal/caudal pelvic bones on which wheelchair users sit, consequently reducing problems such as pressure ulcers, thrombosis and other circulation problems.

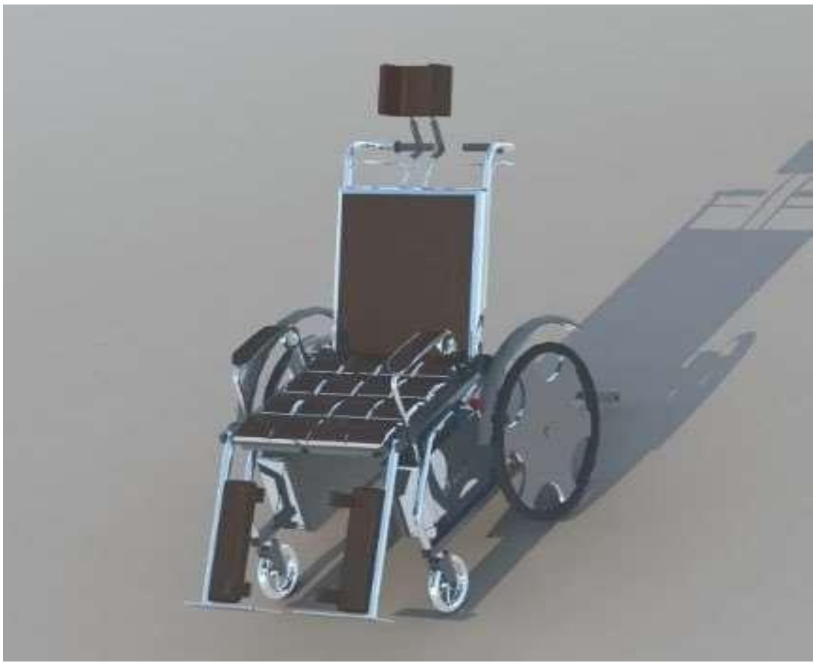
Some of the other benefits the system provides are: Increasing blood flow or regulating blood pressure, improving eating, controlling head and trunk, improving breathing, positioning correctly for function or ease of transfer, adjusting the field of vision, helping with sleep and rest, minimizing muscle tone.

The wheelchair developed aims, in addition to proposing a system of ideal inclinations of the seat and backrest, to meet the needs of the patient according to their clinical condition, and therefore the individual has the possibility of choosing the accessories to be attached to the equipment. For this, the product was designed following the concept of interchangeability of parts, where interchangeable quick couplings were developed so that the accessories are properly coupled.

Being a product project suitable for Production Engineering, we developed from one of the principles of Industry 4.0, modularity. To meet the maximum demand of wheelchair users, the chair was first divided into two large blocks: the single block (wheelchair with tilt system) and the accessory block. Subsequently, adding modularity, the project was broken down into 3 modules (Support, Health and Accessibility and Mobility).

Figure 26 shows the chair with the "Supports" module

Figure 26 - Chair Model



Source: Authors

The Support module was fragmented according to the lower and upper limbs as follows:

- Armrests (Figures 27 and Figure 28)
- Leg support (Figure 29 and Figure 30)

- Footrest (Figure 31and Figure 32)
- Headrest (Figure 33, Figure 34 and Figure 35)

Figure 27 – Armrest with belt

Source: Authors

Figure 28 - Armrests

Source: (ORTO PONTO, [n.d.])

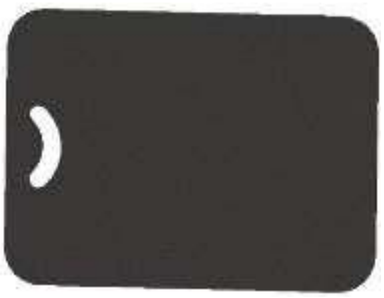
Figure 29 - Leg support with belt

Source: Authors

Figure 30 – Leg and foot support

Source: (SOS MATERIAIS HOSPITALARES, [s.d.])

Figure 31 – Footrest



Source: Authors

Figure 32 - Footrest

Source: (SOS MATERIAIS HOSPITALARES, [s.d.])

Figure 33 – Headrest 1

Source: (IMPORTS BABY, [n.d.])

Figure 34 - Headrest 2

Source: (MEDICAL EXPO, [n.d.])

Figure 35 - Headrest 3

Source: Authors

Figure 36 shows the chair with the "Health" module.

Figure 36 - Wheelchair: Health

Source: Authors

The Health module includes 3 accessories (Figure 37, Figure 38 and Figure 39):

Figure 37 - Serum/Medication/Blood Support

Source: Authors

Figure 38 - Oxygen tank holder

Source: Authors

Figure 39 - Seat belt

Source: (MEDICAL EXPO, [n.d.])

Figure 40 shows the chair with the "Accessibility and Mobility" module.

Figure 40 - Complete chair: Accessibility and Mobility

Source: Authors

Figure 41 - Umbrella Holder

Source: Authors

Figure 42 - Wheels

Source: Authors

Figure 43 - Cup holder

Source: Authors

Figure 44 - Multipurpose table

Source: Authors

Figure 45 - Front wheel

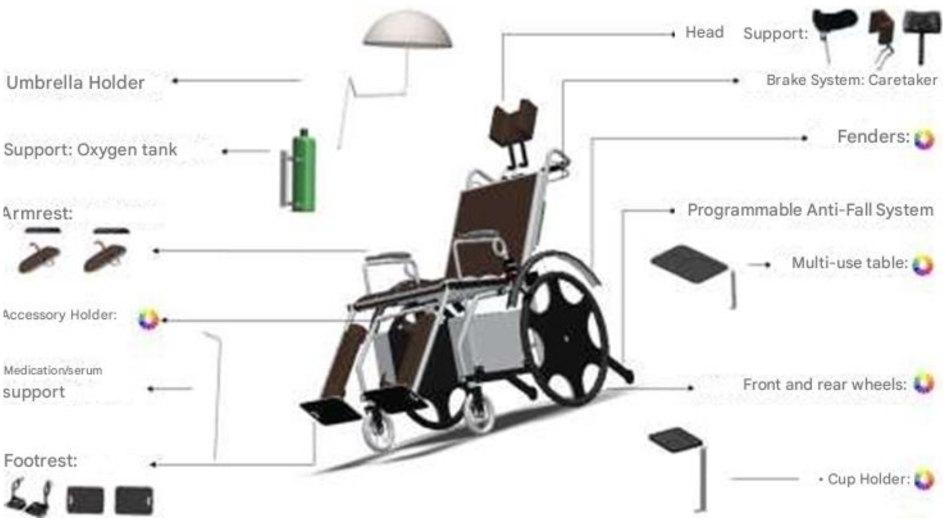
Source: Authors

Figure 46 - Accessory holder

Source: Authors

The support accessories were developed following the folding design concept. According to Jackson (2011), the *folding* concept refers to the use of folding techniques in equipment, aiming at the creation of new products that meet production, transportation, storage and flexible use needs. Therefore, accessories such as IV holders, umbrella holders, multipurpose tables, cup holders and oxygen tank adapters can be folded to facilitate storage in the accessory holder, located inside the wheelchair, which can be seen (with all its components and accessories) in Figure 47.

Figure 47 - Projected wheelchair.

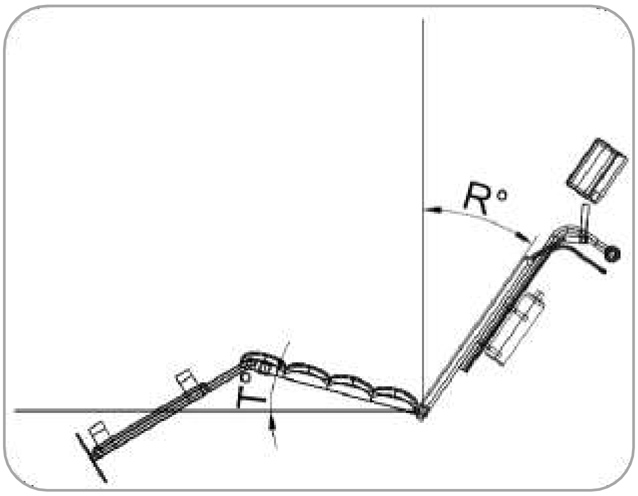


Source: Authors

ERGONOMIC AND PHYSIOLOGICAL ANALYSIS OF THE ENGINEERED WHEELCHAIR

According to a study published by the Institute of Biomechanics of Zurich (ZEMP et al., 2019), wheelchairs that incorporate seat and backrest tilt functions, called *"tilt n space"* are routinely prescribed to redistribute blood pressure and improve circulation problems. In the study, five different seat tilt angles (5°, 15°, 25°, 35°, and 45°), described as *T-angle*, were evaluated in combination with three different backrest recline angles (5°, 15°, and 30°), described as *R-angle*. The outline of the slopes can be seen in Figure 48.

Figure 48 - Inclinations of the backrest and seat.

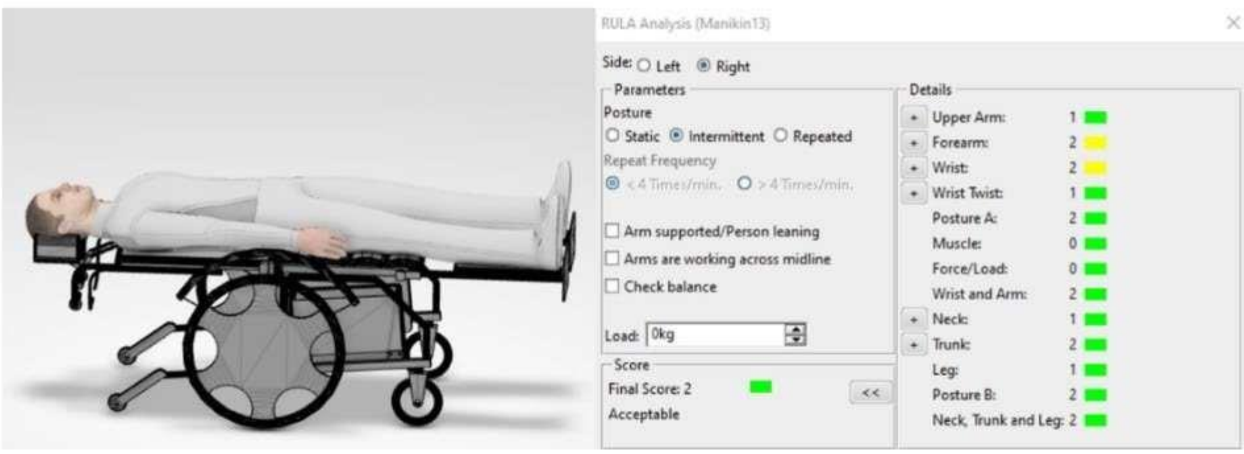


Source: Authors

Although the physiological benefit is evident for the proposed angular combination, the ergonomic behavior of the system was not evaluated. Therefore, in addition to the sitting and lying position, the combination of five different angles of these seat inclinations (5°, 15°, 25°, 35° and 45°) were evaluated in combination with three different angles of backrest recline (5°, 15° and 30°), with the aim of verifying whether there is an ergonomic improvement in the designed product. The tool used for the analysis was the Ergonomics software, present in the Dassault Systemes environment, 3DEXPERIENCE.

In order for the comparison and validation of the hypothesis to be effective, the same mannequins used in the analysis of the conventional wheelchair were evaluated, as evidenced in the images below. The RULA methodology was applied and the results obtained are next to each of the suggested positions, as shown in Figure 49 to Figure 80.

Figure 49 - Chair in position 0° T and 90° R



Source: Authors

Figure 50 - Chair in position 0° T and 90° R

Source: Authors

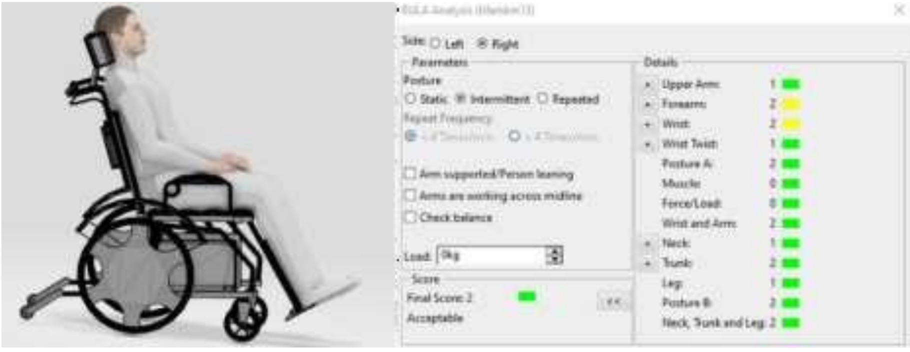
Figure 51 - Chair in position 5° T and 10° R

Source: Authors

Figure 52 - Chair in position 5° T and 10° R

Source: Authors

Figure 53- Chair in position 5° T and 20° R



Source: Authors

Figure 54 - Chair in position 5° T and 20° R

Source: Authors

Figure 55 - Chair in position 5° T and 30° R

Source: Authors

Figure 56 - Chair in position 5° T and 30° R

Source: Authors

Figure 57 - Chair in position 15° T and 20° R

Source: Authors

Figure 58 - Chair in position 15° T and 20° R

Source: Authors

Figure 59 - Chair in position 15° T and 30° R

Source: Authors

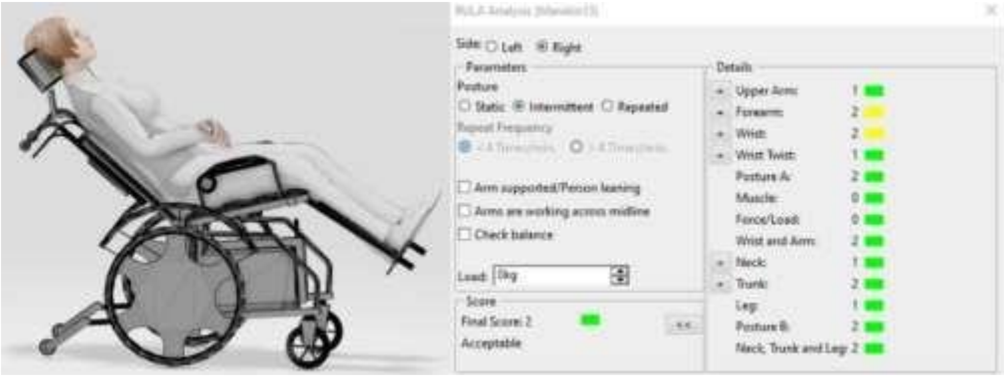
Figure 60 - Chair in position 15° T and 30° R

Source: Authors

Figure 61 - Chair in position 15° T and 45° R

Source: Authors

Figure 62 - Chair in position 15° T and 45° R

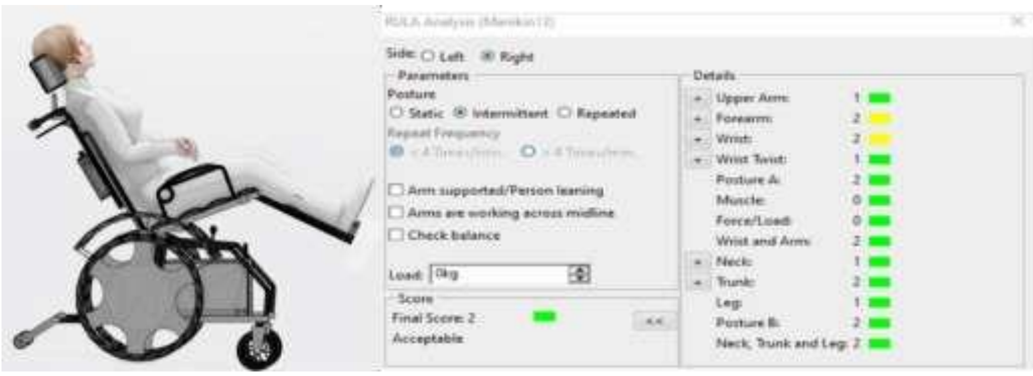


Source: Authors

Figure 63 - Chair in position 25° T and 30° R

Source: Authors

Figure 64 - Chair in position 25° T and 30° R

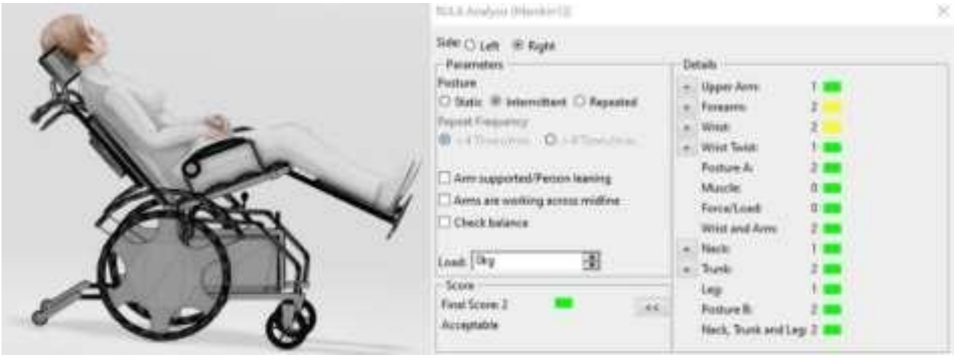


Source: Authors

Figure 65 - Chair in position 25° T and 40° R

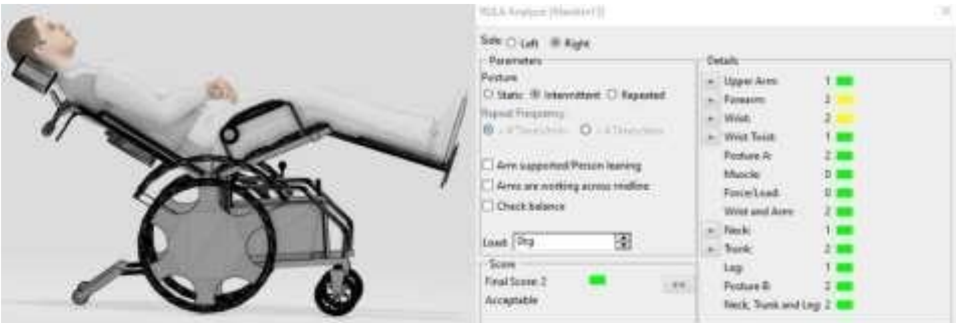
Source: Authors

Figure 66 - Chair in position 25° T and 40° R



Source: Authors

Figure 67 - Chair in position 25° T and 55° R

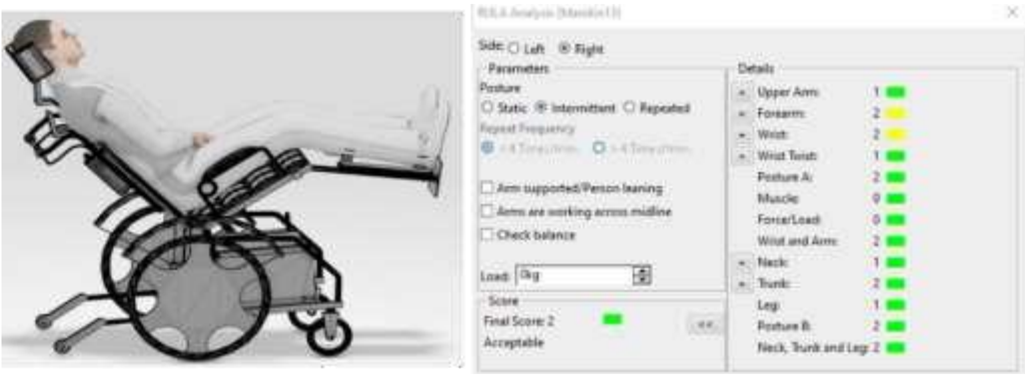


Source: Authors

Figure 68 - Chair in position 25° T and 55° R

Source: Authors

Figure 69 - Chair in position 35° T and 40° R

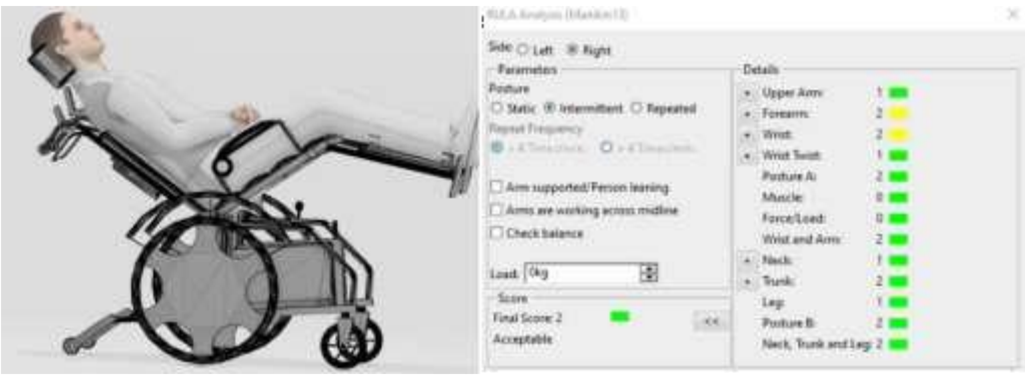


Source: Authors

Figure 70 - Chair in position 35° T and 40° R

Source: Authors

Figure 71 - Chair in position 35° T and 50° R

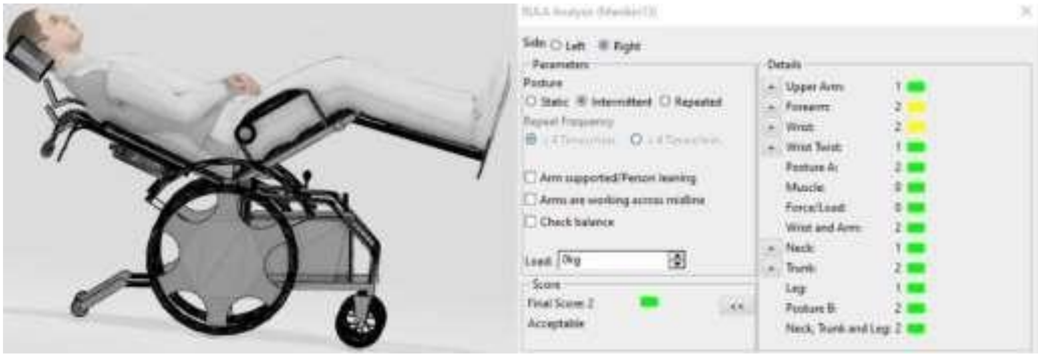


Source: Authors

Figure 72 - Chair in position 35° T and 50° R

Source: Authors

Figure 73 - Chair in position 35° T and 65° R



Source: Authors

Figure 74 - Chair in position 35° T and 65° R

Source: Authors

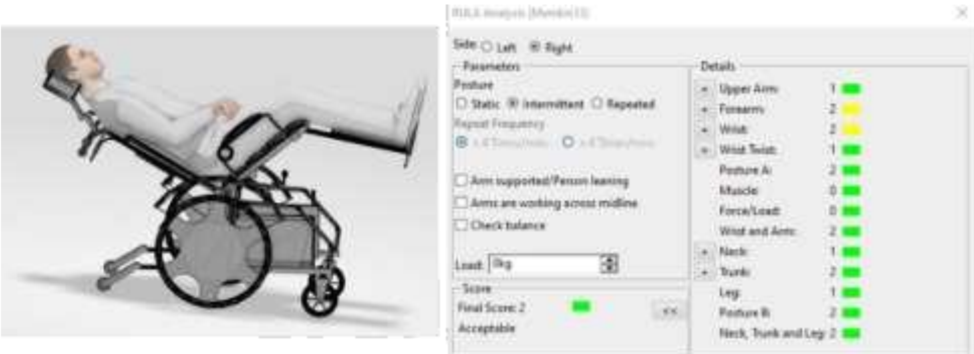
Figure 75 - Chair in position 45° T and 50° R

Source: Authors

Figure 76 - Chair in position 45° T and 50° R

Source: Authors

Figure 77 - Chair in position 45° T and 60° R



Source: Authors

Figure 78 - Chair in position 45° T and 60° R

Source: Authors

Figure 79 - Chair in position 45° T and 75° R

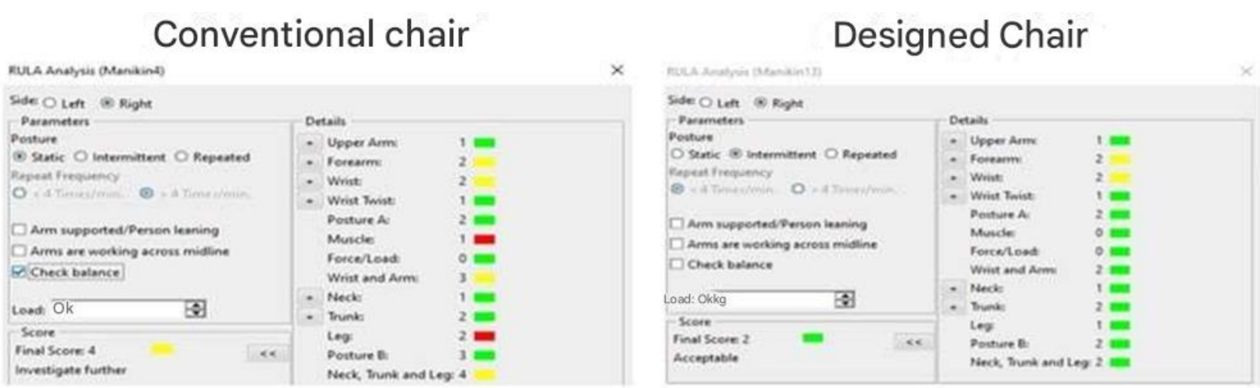
Source: Authors

Figure 80 - Chair in position 45° T and 75° R

Source: Authors

From the ergonomic analysis, it can be observed that, for all the suggested combinations of seat and backrest angles, as well as for the sitting and lying position, there was an ergonomic benefit since, through the RULA methodology, the intervention level was classified as grade 2, which was described as "Acceptable Posture".

Figure 81 shows the comparison between the conventional wheelchair and the designed wheelchair. Figure 81 - Comparison of results: Conventional chair vs. Projected chair



Source: Authors

The biggest difference occurs in muscle activity because, due to the intermittency in the activity, the impact on the muscles of the body is smaller, as changes in inclinations are possible throughout the day and, as a consequence, the score goes from 1 in the conventional chair to 0 in the projected wheelchair.

The positioning of the legs also obtained a significant gain. The RULA methodology classifies the absence of leg support as score 2 and the presence of support and the possibility of adjusting leg and foot support according to the patient's size as score 1.

Thus, the ergonomic benefit was evidenced by changing the degree of postural risk from grade 4 (Changes may be necessary) to grade 2 (Acceptable posture).

4. CONCLUSIONS

Considering that the objective of the work was to propose an intervention and perform an ergonomic analysis in a wheelchair with an inclination system, it can be concluded that, according to the RULA methodology, the conventional wheelchair demonstrates ergonomic problems that can result in disorders, especially in the region of the arms and legs, in addition to muscular difficulties resulting from excessive permanence in the sitting position.

In addition, the process of removing the patient by the caregiver presents a high risk. As a first solution, the impact of making the armrests of the chair removable was analyzed, with the aim of assisting the removal of the patient by the caregiver. The application of the REBA methodology showed an ergonomic benefit, since the risk classification after making the armrest removable was changed from "Very High Risk" to "Medium Risk".

After verifying the increase in disability in Brazil and the immersion and ideation carried out after interviews with the target audience, a product was developed that meets the needs of wheelchair users and their respective caregivers.

The analysis of the projected wheelchair shows physiological benefits, considering that, when compared to the reference posture in the upright position (sitting), all positions, except 15° backrest / 5° recline, result in a significant decrease in pressure and improved circulation, reducing health problems arising from the permanence in the sitting position.

Regarding ergonomics, the comparison of all the suggested angular combinations, as well as the reference posture (sitting) and lying down, showed, according to the RULA methodology, a change in the degree of intervention from "Changes may be necessary" to "Acceptable posture", evidencing the ergonomic benefit of the designed wheelchair.

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