STUDY AND PRODUCT DESIGN FOR THE ERGONOMIC VIABILITY OF A WHEELCHAIR WITH TILT-IN-SPACE SYSTEM

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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 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 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.

INTRODUCTION

According to data from the IBGE Demographic Census, more than 45 million people (23.9% of the total population) in Brazil declare themselves to have some form of visual, auditory, mental, or motor disability, with motor disability accounting for approximately 7% of the population (around 30% of individuals with disabilities) in the country (IBGE, 2010; IBGE EDUCA, [n.d.]).

To address a motor disability, whether temporary or permanent, the use of a wheelchair may be necessary. It should provide the best ergonomic and physiological comfort for the individual, thereby reducing ailments derived from their initial condition.

The transfer of the patient by the caregiver should also be analyzed to reduce risks in all activities related to a wheelchair. Ergonomic methodologies such as RULA and REBA can be used to analyze the ergonomics of both the wheelchair user and the caregiver. These methods assess the patient's posture in the equipment and the risk involved in transferring the patient by the caregiver, justifying the need for this study.

A wheelchair with a tilt-in-space system does not define the ergonomically ideal inclinations for the patient, only the seated position and inclinations determined by the patient or caregiver. Incorrect inclinations can lead to health complications, such as poor blood circulation, muscle atrophy, or postural problems.

Therefore, the aim of this study was to propose an intervention and conduct an ergonomic analysis of a wheelchair with a tilt-in-space system. The project seeks to ensure that the product can provide the necessary ergonomics for individuals with restricted movement or diseases that limit their mobility, as well as for their respective caregivers.

METHODOLOGY

For the formulation of the questions presented in the questionnaire, the questionnaire development methodology and behavior techniques proposed by Iida and Buarque (2016) were employed. This methodology includes: (1) planning: defining objectives, deadlines, and reliability; (2) sample definition: evaluated considering the target audience, sample size, and sampling procedure; (3) questionnaire construction: list of questions, ordering, layout, and response processing.

The planning phase aimed to collect data from individuals who use wheelchairs or have used them at some point in their lives, as well as professionals in the healthcare field (physiotherapists and doctors). This input was crucial for our ergonomic study to implement improvements based on the needs and desires of the market. To ensure more reliable responses, they were considered anonymous, preserving the individual's identity.

The sample definition was highly filtered, with the assistance of Dr. Silvio Labate Rodrigues and medical students from UNIMES (Santos, SP) who shared the questionnaire with patients and their respective caregivers in clinics and hospitals. As a result, 43 people responded to the questionnaire by June 10, 2019.

Implementing a Likert scale to measure attitudes and assess the degree of compatibility, the questionnaire was strategically organized in the following sequence:

    a) Age

    b) Gender

    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 your patient's limitation?

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

g) How often is the equipment used?

h) How was this wheelchair purchased?

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

j) How do you rate the functionality and comfort of the wheelchair?

k) How do you rate the ergonomics and safety of the wheelchair?

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

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

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

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

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

q) What improvement suggestions do you find 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 conducted to qualitatively understand the effort made by wheelchair users and their respective caregivers. Additionally, a focus group and informal interviews were conducted at the 'Hospitalar Fair 2019' to understand the current scenario of the wheelchair and other physiotherapeutic tools market, gathering qualitative information.

In qualitative assessments, insights were obtained through an interview with physiotherapist Francisco De Paula, revealing that patients often do not prioritize ergonomically ideal positions but rather focus on their immediate comfort. In other words, complications caused by prolonged wheelchair use are often the result of the patient's misuse.

Another aspect highlighted in the conversation was that many caregivers, due to repetitive movements and being with the patient 24 hours a day, end up experiencing complications, especially in the lower back, when handling/transporting the patient from the wheelchair to a bed, table, bathroom, among others.

ERGONOMIC ANALYSIS

A ergonomic work analysis aims to assess, 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 Brazilian legislation in Regulatory Standard 17 (BRASIL, 1978), to evaluate the adaptation of working conditions to the psychological and physiological characteristics of workers, it is the employer's responsibility to conduct ergonomic work analysis, addressing at least the working conditions. Working conditions include aspects related to material handling, transportation, and unloading, furniture, equipment, environmental conditions of the workplace, and the organization of work itself (COUTO, 1996).

This study utilized ergonomic tools to simulate wheelchair users, unlike a traditional workstation. However, due to the prolonged use of the equipment, their activities could be interpreted similarly to all tools used in the project (Dassault-Ergonomics and Ergolandia – RULA and REBA methods).

With a target audience of almost 50% elderly individuals, it was considered that, from the age

of 50 onwards, there is a decrease in static anthropometry due to aging, with a loss of 3cm until the age of 80, resulting in a posture increasingly distant from the ideal and facilitating various complications. The ergonomic analysis proposed by this work is precisely to prevent these problems resulting from prolonged wheelchair use.

As a result of the ergonomic analysis in the object of study of this work, 17 possible adaptations in the wheelchair were mapped, divided into 4 distinct fronts (Table 1):

Table 1 - Mapping of Improvements

Accessibility and Mobility	Safety	Health	Aesthetics
• Accessory Holder • Cup Holder • Umbrella Holder Adapter • "Multipurpose" Table • Foldable Chair • Foldable Armrest Supports to facilitate patient removal/insertion • Ability to migrate controls to the right or left side	• • Increased distance between the rim and wheels Brake system (for the patient and the caregiver) • Anti-fall system located on the wheels • Safety Belt (Trunk/Legs/Arms)	• Cushions with eggshell mattress • Leg massager • Oxygen tank adapter • Adapter/Support for hooks for IV drips/blood, etc..	• Single Block/Single Structure (Seat/Back/Legs) • Customization of Hubcaps and other accessories

Source: Authors

FORMULATION OF THE DIAGNOSIS

Diagnosis aims to identify the reasons leading to the issues mentioned in the demand, task, and activity analysis (ABRAHÃO et al., 2009). Based on the gathered responses, it was evident that caregivers' complaints revolve around fatigue and lower back injuries due to constant movements and prolonged work hours. From the users' perspective, the primary complaint arises from the extended periods spent in the wheelchair, resulting in pressure ulcers and thrombosis, which can lead to new complications in the medium and long term, directly impacting their quality of life and life expectancy. In addition to presenting the collected data, the Ergonomics Software was used for diagnosing by simulating the studied activities in the workplace

ERGONOMIC RECOMMENDATIONS

The recommendations in the study are associated with what needs to be done to solve the diagnosed problem, presenting well-detailed steps for problem resolution (IIDA; BUARQUE, 2016). A redesign of the wheelchair is necessary, considering all variables that interfere with the patient's and caregiver's movement, mobility, and accessibility. In other words, these are recommendations based on the evaluation of micro and macro ergonomics with the aim of presenting viable solutions to the evaluated case study.

RESULTS AND DISCUSSIONS

The survey via questionnaire was conducted with the aim of understanding the profile of individuals who use wheelchairs, seeking to comprehend their needs, reasons for use, attributes, and limitations of the equipment, with the ultimate goal of understanding the ergonomics of the equipment and possible improvements to be implemented. The analysis was divided into six sections, with 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 groups, it is possible to observe that the highest concentration is in the 50 years or older range, with also a

notable presence of individuals in the 20 to 30 years age group.

Figure 1 - Age Range
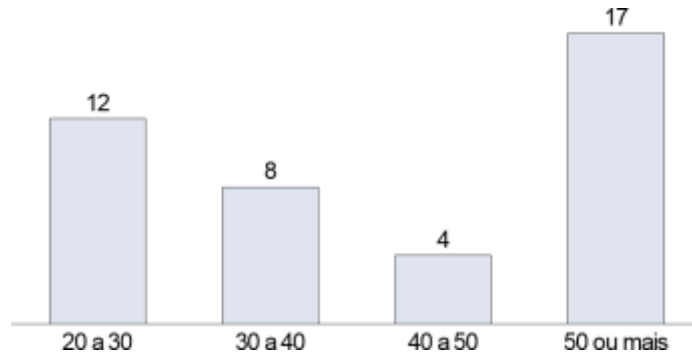
Source: Authors

A distribution by gender, on the other hand, indicates that females represent 63% of the respondents, while males account for a lower percentage (37%). It can be noted that the sample distribution is segmented similarly between users (49%) and caregivers (41%) when comparing respondent profiles. Doctors, in turn, represented 10% of the responses (4 answers), as shown in Figures 2 and 3, respectively.

Figure 2 – Gender
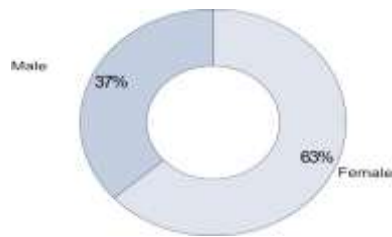
Figure 3 - Respondent

Source: Authors

Source: Authors

A physical limitation is present in almost 50% of the respondents, being the main focus of analysis and implementation of solutions, followed by multiple disabilities, which affect 31.71% of the participants. Motor and mental limitations have a representation of 14.63% and 4.88%, respectively. The responses can be observed in Figure 4. Figure 5, which assesses the degree of limitation, shows that partial limitation represents the majority of the sample, with 34 responses. Seven respondents had total limitation or cared for individuals with this degree of limitation.

Figura 4 - Tipo de limitação
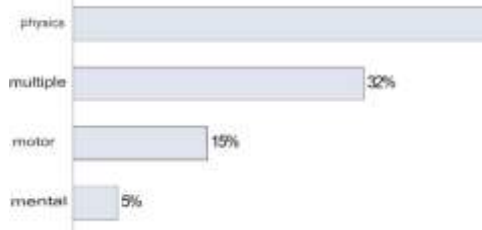
Figura 5 - Grau de limitação
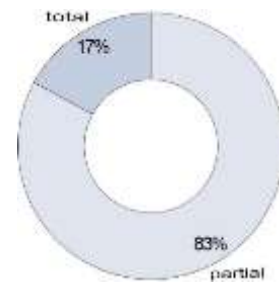
Source: Authors

Source: Authors

Evaluating the reason for using a wheelchair, it is noticeable that age-related limitations represent the main reason for wheelchair use, with a representation of 41.46% of the statistical group (Figure 6). Other illnesses also have high relevance, with 13 responses among the 41 respondents, and the remaining categories combined have 11 responses (26.83%).
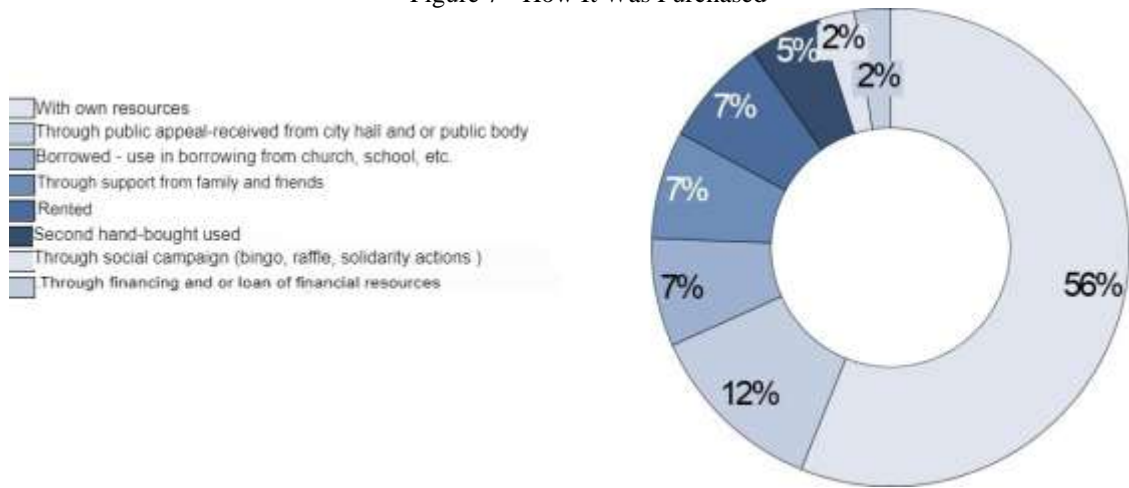
Figure 6 - Reason for Use
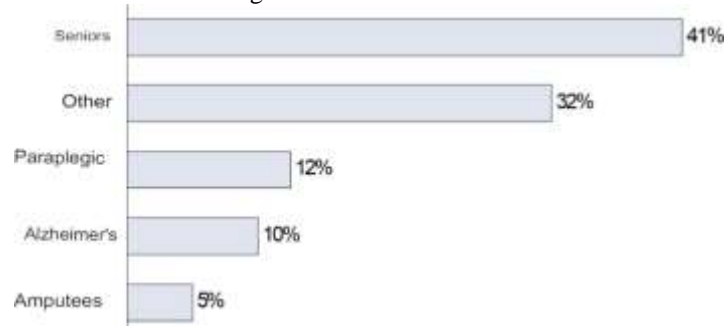
Source: Authors

The third block aims to analyze the general aspects of the wheelchair for the respondents, aiming to understand the general functionalities of the equipment and map its respective purchase process and frequency of use.

From the analysis of Figure 7, it is possible to perceive that more than half of the sample acquired the wheelchair with their own resources (56.10%). Receiving it for free through donations from a public entity also has a significant representation (12.20%), while the remaining options (Rent, Family and friends, social campaign, loan, or financing) add up to 31.7%.
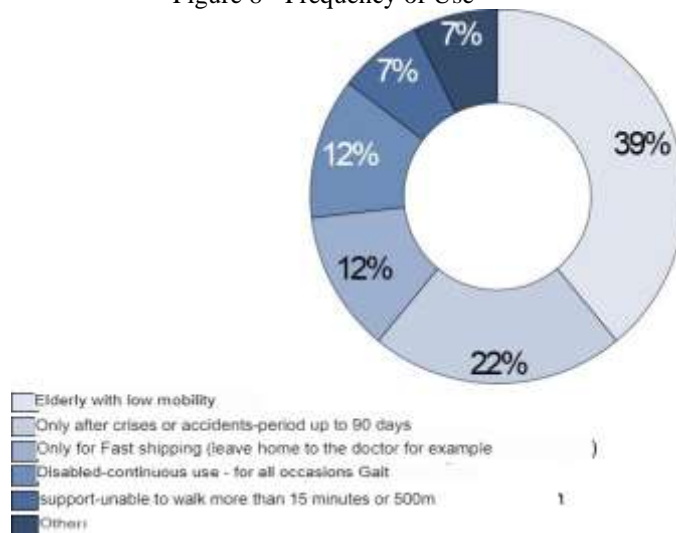
Figure 7 - How It Was Purchased

- With own resources
- Through public appeal-received from city hall and or public body
- Borrowed - use in borrowing from church, school, etc.
- Through support from family and friends
- Rented
- Second hand-bought used
- Through social campaign (bingo, raffle, solidarity actions)
- Through financing and or loan of financial resources

Source: Authors

The frequency of use shows that among the 41 respondents, 39% (16 people) indicated that they are elderly with low mobility or caregivers for the elderly. Continuous use and use only for quick transportation each represent 12.10% of the responses, with 5 people each (Figure 8).

Figure 8 - Frequency of Use

- Elderly with low mobility
- Only after crises or accidents-period up to 90 days
- Only for Fast shipping (leave home to the doctor for example)
- Disabled-continuous use - for all occasions Gait
- support-unable to walk more than 15 minutes or 500m
- Other

Source: Authors

In terms of the functionality of the wheelchair, Figure 9 shows that, when combining the categories 'regular' and 'poor,' 63.42% of the respondents admit that the equipment has some issues. It's worth noting that less than 5% classify their wheelchair as excellent.

Figure 10 shows that weight, on the other hand, is not the main concern in the evaluation of the equipment, as 29.27% consider it light, and 51.22% believe that a person can lift the wheelchair with some effort

Figure 9 - Equipment functionality
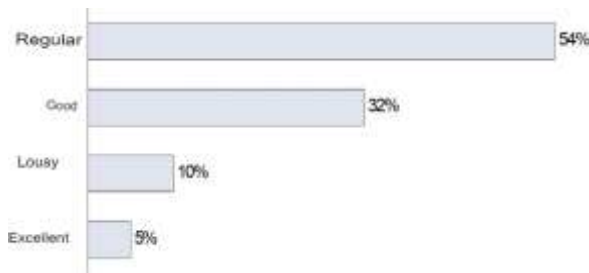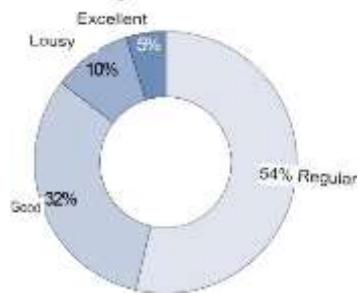

Source: Authors

Figure 10 - Equipment Weight
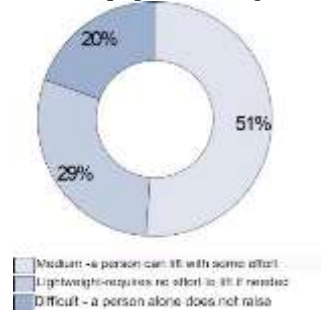
Source: Authors

The fourth block aims to understand the product's ergonomics, aiming to map the accessibility and ergonomic quality of the product, as well as to understand the importance of implementing an ideal tilting system.

Figure 11 shows that, when the Regular (53.66%) and Poor (12.20%) ratings are combined, it is evident that for the majority of the sample, the wheelchair's ergonomics needs improvement. When we analyze the accessibility of support equipment for wheelchair users, as shown in Figure 12, 21.95% rate them as poor, and 56.10% as regular, representing, therefore, one of the main bottlenecks of the product and consequently, a focus of this work. For both criteria, only 2.44% consider the wheelchair Excellent.

Figure 11 - Ergonomics of the current wheelchair

Source: Authors

Figure 12 - Accessibility of support equipment
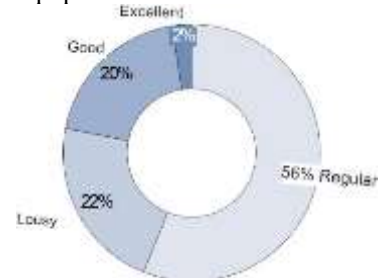
Source: Authors

Regarding the implementation of a tilting system and the definition of ideal positions, it can be observed that the inclination theme represents a significant factor for 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 important in a wheelchair, while 73.17% consider the attribute very important. With regard to defining ergonomically ideal positions, 90.24% of the interviewed individuals 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 tilting system.
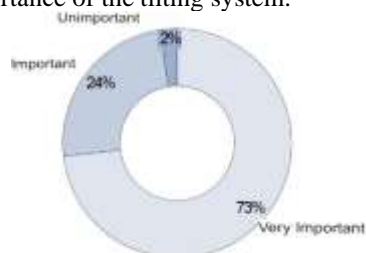
Source: Authors

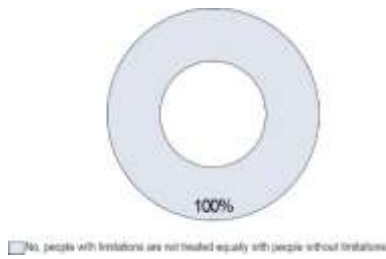Figure 14 - Relevance of a tilting system
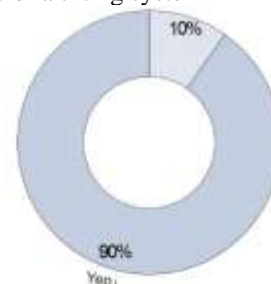
Source: Authors

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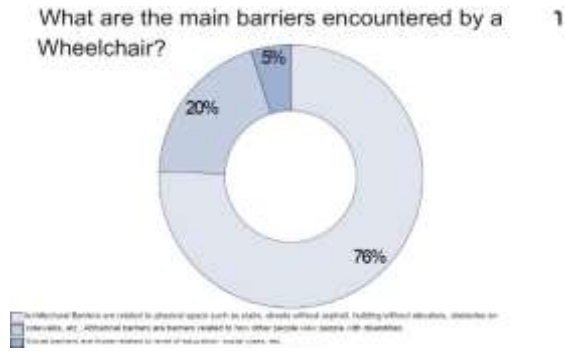
some type of limitation are not treated equally to those without limitations, while Figure 16 shows that, in the case of wheelchair users, 31 respondents (75.61%) see architectural barriers as the main problem to be solved
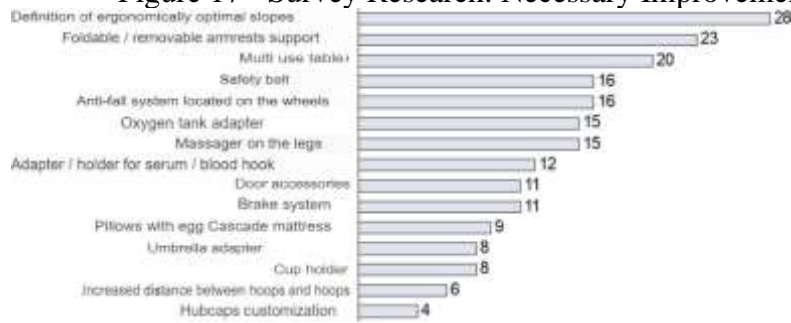
Figure 15 - Treatment of wheelchair users   Figure 16 - Main barriers encountered

What are the main barriers encountered by a   1
Wheelchair?

100%

☐ No, people with limitations are not treated equally with people without limitations

☐ Architectural Barriers are related to physical space (such as stairs, streets without asphalt, building without elevators, obstacles on sidewalks, etc.) Attitudinal barriers are barriers related to how other people view people with disabilities

☐ Social barriers are those related to denial of education, social access, etc.

Source: Authors   Source: Authors

The sixth and final block of responses aims to identify the most relevant improvements in terms of accessibility and functionality for the wheelchair to meet the needs of the wheelchair user and their respective caregiver. The analysis of the responses in Figure 17 revealed 16 possible improvements to be implemented, with the main highlights being the definition of ideal tilts via remote control, multi-purpose table, foldable or removable armrest support, seatbelt, and anti-fall system.

Figure 17 - Survey Research: Necessary Improvements

Improvement	Count
Definition of ergonomically optimal slopes	28
Foldable / removable armrests support	23
Multi use table	20
Safety belt	16
Anti-fall system located on the wheels	16
Oxygen tank adapter	15
Massager on the legs	15
Adapter / holder for serum / blood hook	12
Door accessories	11
Brake system	11
Pillows with egg Cascade mattress	9
Umbrella adapter	8
Cup holder	8
Increased distance between hoops and hoops	6
Hubcaps customization	4

Source: Authors

After the immersion and analysis conducted through the questionnaire responses, the ergonomics of the conventional wheelchair and the impact of removing the armrests to facilitate the patient's transportation by the caregiver were examined.

ANALYSIS OF THE CONVENTIONAL WHEELCHAIR

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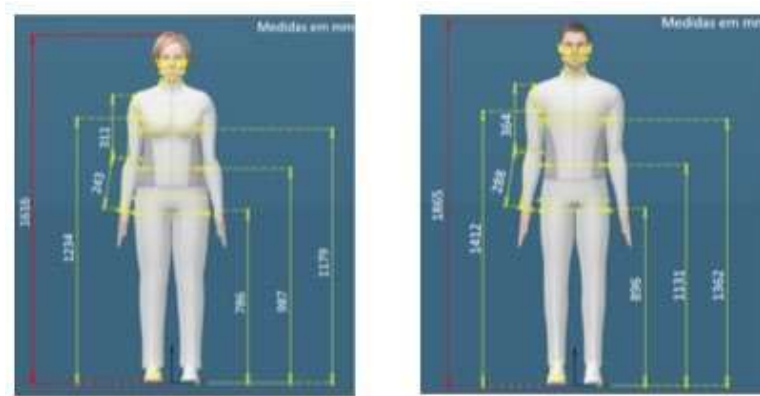
Figure 18 - Conventional wheelchair

Source: Authors

Two types of mannequins were tested to elucidate differences in height and weight among the general population. For the parameterization of the study, we selected one female and one male mannequin. Their dimensions are shown in Figure 19.

Figure 19 - Dimensions of the mannequins

Source: Authors

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

Figure 20 - Mannequin positioning

Source: Authors

We can observe that, due to its height, the mannequin is unable to position its legs and feet correctly as it does not reach the footrests. When analyzing the arm position, there is a clear distance between the wheelchair armrest and the ideal arm position, resulting in ergonomic losses in the mannequin's posture. The results obtained by applying the RULA methodology to the mannequin are shown in Figure 21.

Figure 21 - Result - RULA Methodology for the conventional wheelchair
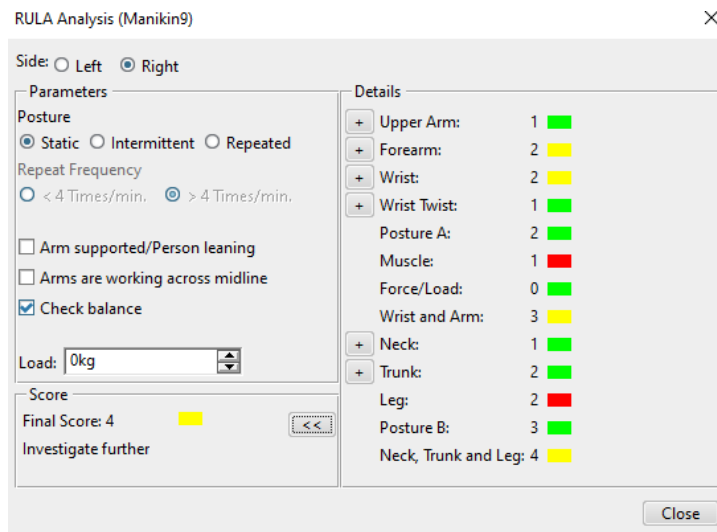
Source: Authors

The analysis is conducted under the condition that the mannequin remains static in position. The indications in green explicitly show the positioning of the upper arm, wrist twist, neck, and trunk. The three limbs analyzed separately are at an ergonomically acceptable level according to the RULA methodology. The indices in yellow, apparent in the forearm and wrist separately, along with the entire arm combined with the wrist, demonstrate that, due to the lack of correct support for the mannequin, scores of 2 and 3 were incurred, respectively. Finally, the combined analysis of the legs, trunk, and neck indicates the poor adaptability of the wheelchair to the female mannequin's body, resulting in unnecessary efforts and leading to an overall analysis result of level 4, where the RULA methodology suggests that "changes may be necessary."

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

Figure 22 - Mannequin positioning

Source: Authors

It can be observed that, due to its height, the mannequin is also unable to accommodate the elbows and the entire arm's extension (due to the lack of height adjustment in the armrests for different types of users). Its legs fit into the footrest, but only with a certain leg angle, resulting in a non-ideal posture in the seat support and leg length. The results obtained by applying the RULA methodology to the mannequin are indicated in Figure 23.

Figure 23 - Result - RULA Methodology for the conventional wheelchair

Source: Authors

The results are very similar to those found with the mannequin of different height and gender, also classified by the RULA methodology as level 4, indicating the need for observations and the possibility of changes.

PATIENT REMOVAL BY THE CAREGIVER

In order to improve the ergonomics in the process of patient removal by their respective caregiver, the removal of the armrests was suggested. To assess the effectiveness of this action, the REBA methodology was applied using the Ergolandia software, indicating the results in Figure 24 and Figure 25.

1 - Diagnosis of the caregiver in a conventional wheelchair:

Figure 24 - REBA: Result for the wheelchair with armrests

Source: Authors

2 - Diagnosis of the caregiver in a wheelchair with tilt and removable armrest:

Figure 25 - Result - REBA Methodology: Result without armrests
Source: Authors, 2019

Source: Authors, 2019

From the analysis of the REBA methodology, a significant improvement in the process is observed after the removal of the armrests. Initially, the result indicated a score of 12, leading to immediate intervention and a very high risk. After the proposal to remove the armrest, the process now has a moderate risk, still requiring intervention but to a lesser extent.

PRODUCT DEVELOPMENT

Considering the ergonomic benefit resulting from the removal of the armrests and the improvements in accessibility and functionality mapped from the conducted questionnaire, a new product was developed in the SolidWorks software. The aim was to address all the proposed suggestions and incorporate a tilting system that defines positions ergonomically and physiologically ideal, utilizing the tilting system of the backrest and seat for its implementation.

The designed system systematically changes the orientation of someone sitting in a wheelchair while maintaining equal angles of the hip, knee, and ankle. The primary goal of the system is to redistribute pressures or loads on the body, particularly on the tuberosities and ischial or distal/caudal pelvic bones where wheelchair users sit, consequently reducing issues such as pressure ulcers, thrombosis, and other circulation problems.

Some of the other benefits that the system provides include increasing blood flow or regulating blood pressure, improving digestion, controlling head and trunk position, enhancing breathing, positioning correctly for function or ease of transfer, adjusting the field of vision, aiding in sleep and rest, and minimizing muscle tone.

The developed wheelchair aims not only to propose a system of ideal seat and backrest tilting but also to meet the patient's needs according to their clinical condition. Therefore, individuals have the option to choose the accessories to be attached to the equipment. For this purpose, the product was designed following the concept of interchangeability of parts, where quick interchangeable connectors were developed for accessories to be properly attached.

Being a product design suitable for Production Engineering, we developed it based on one of the principles of Industry 4.0, modularity. To meet the maximum demand of wheelchair users, the wheelchair was initially divided into two major blocks: a single block (wheelchair with tilting system) and the accessories block. Subsequently, adding modularity, the project was divided into 3 modules (Supports, Health and Accessibility, and Mobility).

Figure 26 presents the wheelchair with the "Supports" module.

Figure 26 - Chair Model
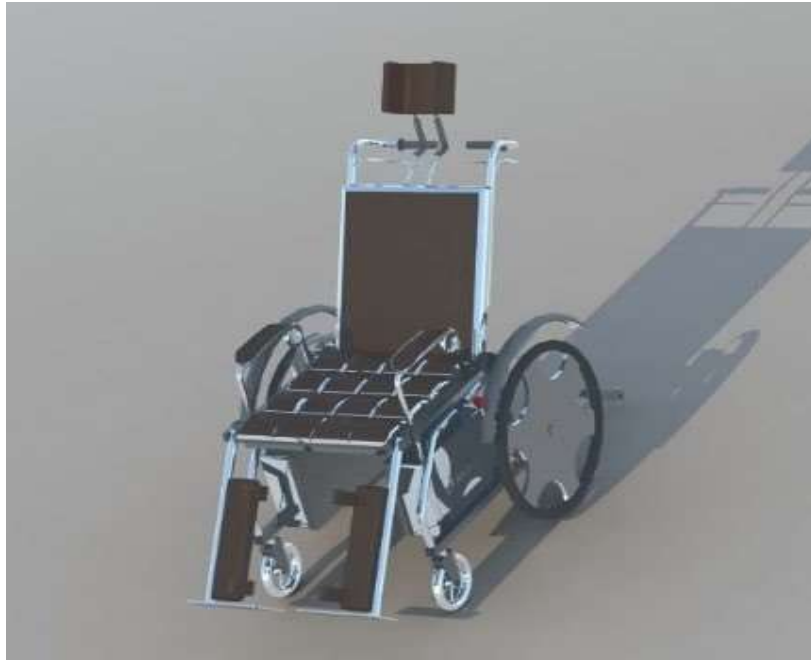
Source: Authors

The Supports module was divided according to the lower and upper limbs as follows:

- Armrest support (Figure 27 and Figure 28)

- Leg support (Figure 29 and Figure 30)

- Footrest support (Figure 31 and Figure 32)

- Headrest support (Figure 33, Figure 34, and Figure 35)

Figure 27 - Armrest support with belt   Figure 28 - Armrest support

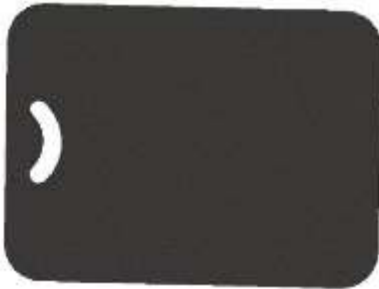Source: (ORTO PONTO, [s.d.])

Source: Authors

Figure 29 - Leg support with belt

Source: Authors

Figure 30 - Leg and foot support

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

Figure 31 - Footrest support

Source: Authors

Figure 32 - Footrest support

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

Figure 33 - Headrest support 1

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

Figure 34 - Headrest support 2

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

Figure 35 - Headrest support 3

Source: Authors

Figure 36 presents the wheelchair 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 - Support for IV Drip/Medication/Blood

Figure 38 - Oxygen tank holder

Figure 39 - Safety belt

Source: Authors

Source: Authors

Fonte: (MEDICAL EXPO, [s.d.])

Figure 40 presents the wheelchair with the "Accessibility and Mobility module.

Figure 40 - Complete wheelchair: Accessibility and Mobility

Source: Authors

Figura 41 – Umbrella holder

Source: Authors

Figura 42 - Wheels

Source: Authors

Figura 43 - Coaster

Source: Authors

Figura 44 – Multipurpose table

Source: Authors

Figura 45 – Front wheel

Source: Authors

Figura 46 – Accessory holder

Source: Authors

The support accessories were developed following the concept of folding design. According to Jackson (2011), the folding concept involves the use of folding techniques in equipment, aiming to create new products that meet production, transportation, storage, and flexible use needs. Therefore, accessories such as IV drip holder, umbrella holder, multi-purpose table, cup holder, and oxygen tank adapter can be folded for easy storage in the accessory holder, located inside the wheelchair, as shown with all its components and accessories in Figures 47.

Figura 47 – Designed wheelchair
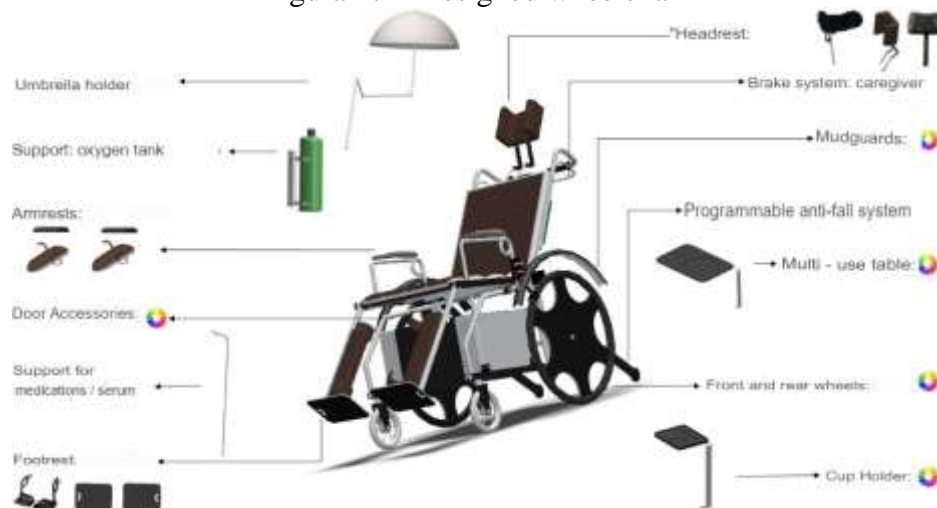
Source: Authors

ERGONOMIC AND PHYSIOLOGICAL ANALYSIS OF THE DESIGNED WHEELCHAIR

According to a study published by the Institute of Biomechanics in Zurich (ZEMP et al., 2019), wheelchairs that incorporate seat and backrest tilt functions, referred to as "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°), referred to as the T angle, were evaluated in combination with three different backrest recline angles (5°,

15°, and 30°), referred to as the R angle. The schematics of the tilts can be seen in Figure 48.

Figure 48 – Tilt of the backrest and seat
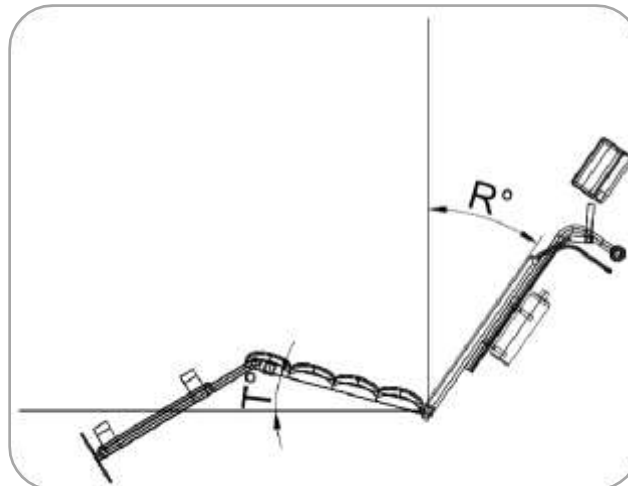
Source: Authors

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

For effective comparison and validation of the hypothesis, the same mannequins used in the conventional wheelchair analysis were evaluated, as shown 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.

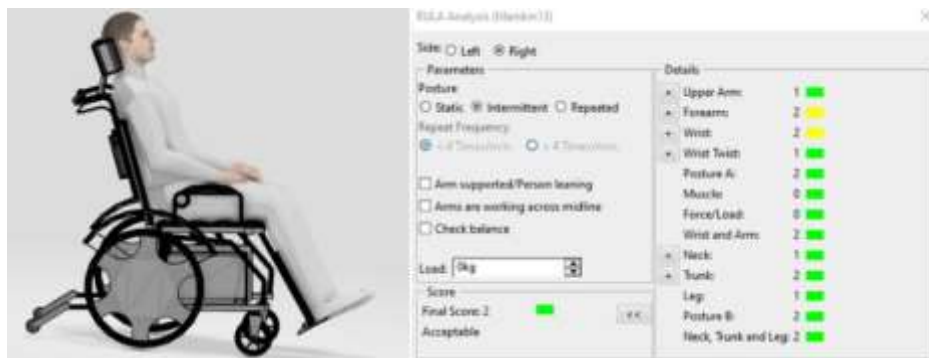Figure 49 – Chair in position 0° T e 90° R
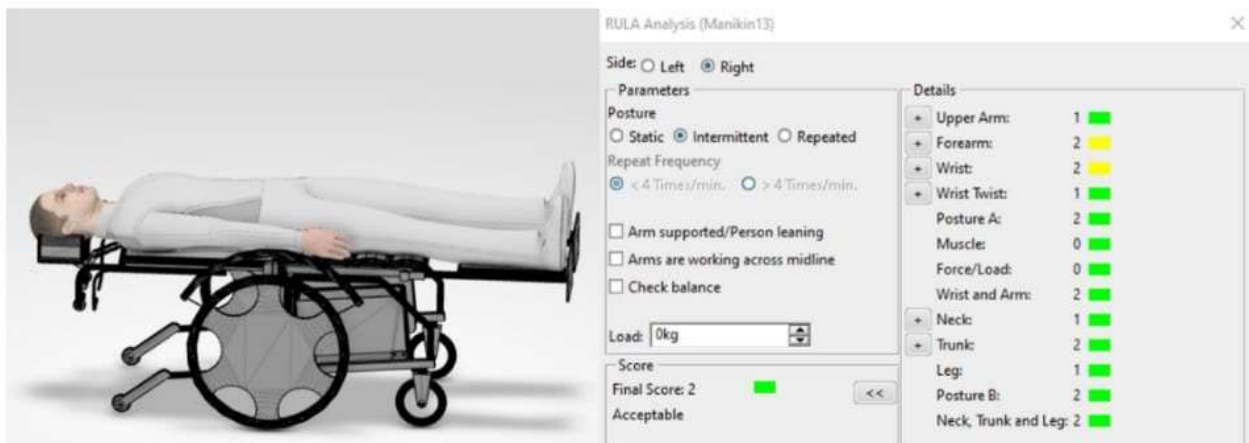
Source: Authors
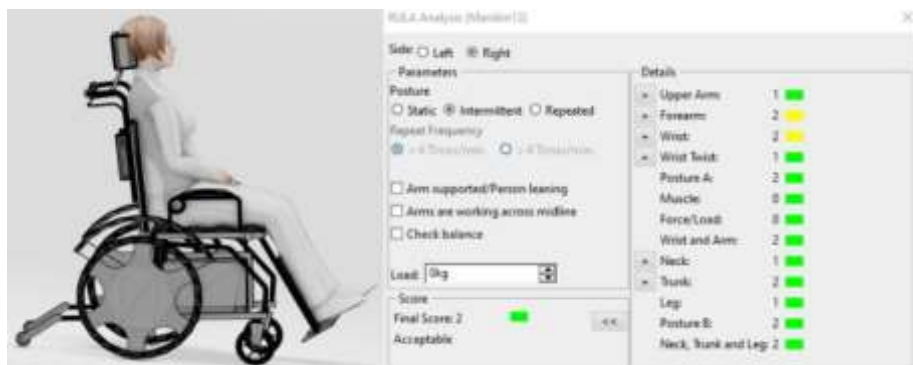
Figura 50 - Cadeira na posição 0° T e 90° R

Fonte: Autores

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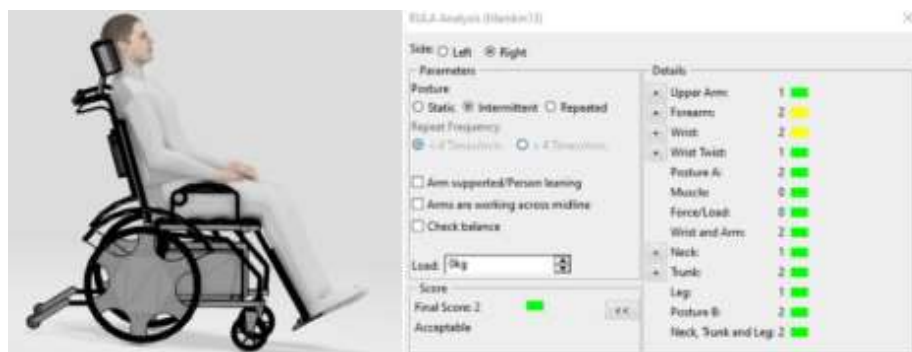

Source: Authors

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

Source: Authors

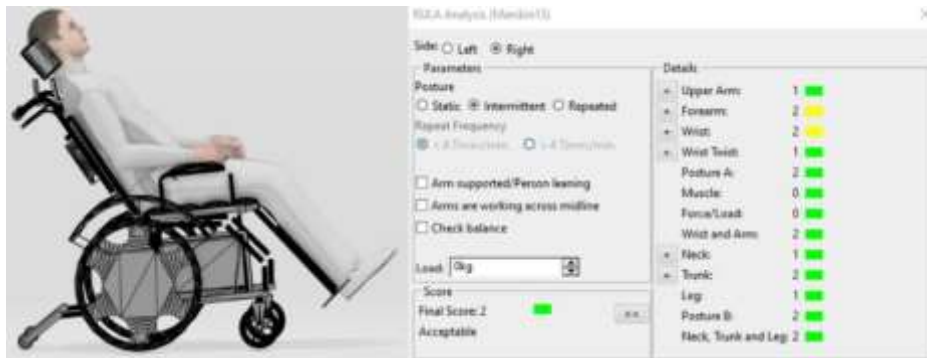Figure 53- Chair in position 5° T e 20° R

Source: Authors

Figura 54 - Cadeira na posição 5° T e 20° R

Source: Authors

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

Source: Authors

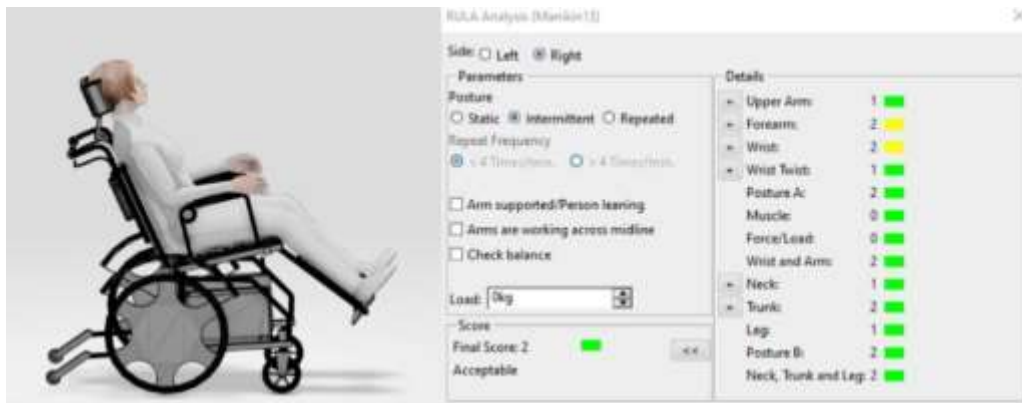Figure 56 - Chair in position 5° T e 30° R

Source: Authors

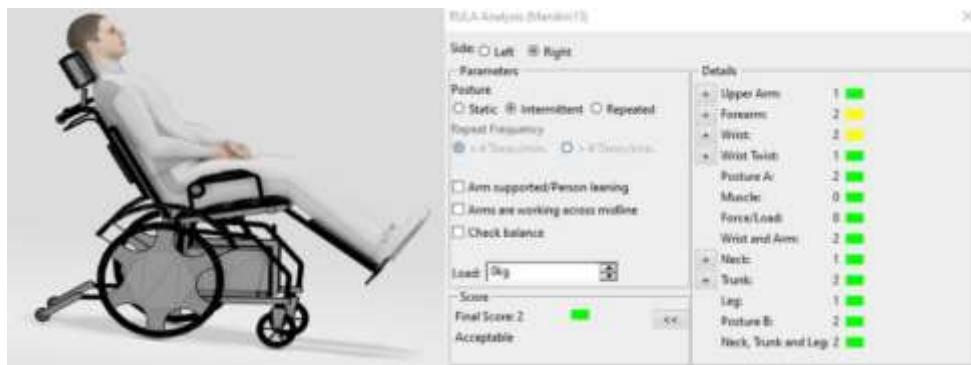Figure 57 - Chair in position 15° T e 20° R

Source: Authors

Figura 58 - Cadeira na posição 15° T e 20° R

Source: Authors

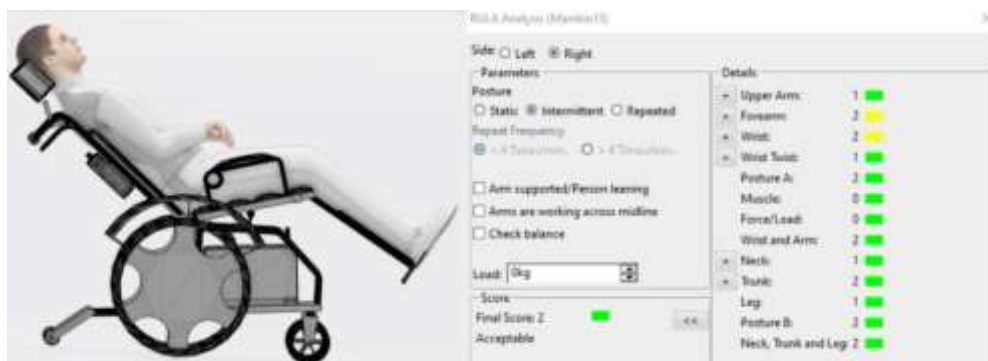Figure 59 - Chair in position 15° T e 30° R

Source: Authors

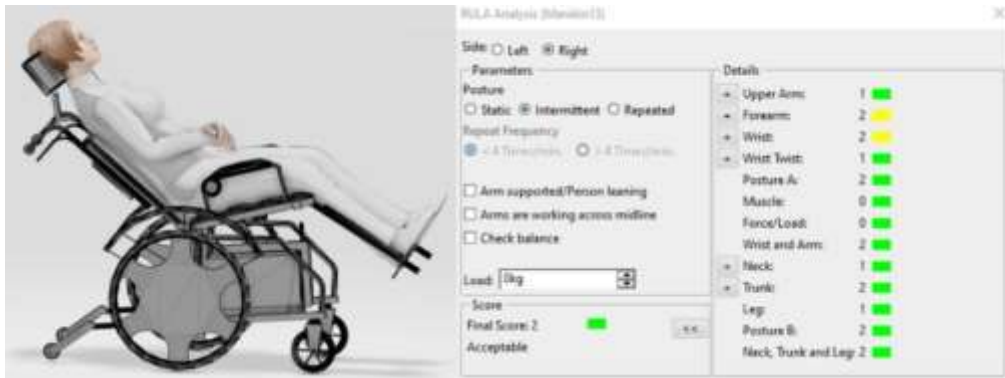Figure 60 - Chair in position 15° T e 30° R

Source: Authors

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

Source: Authors

Figura 62 - Cadeira na posição 15° T e 45° R

Source: Authors

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

Source: Authors
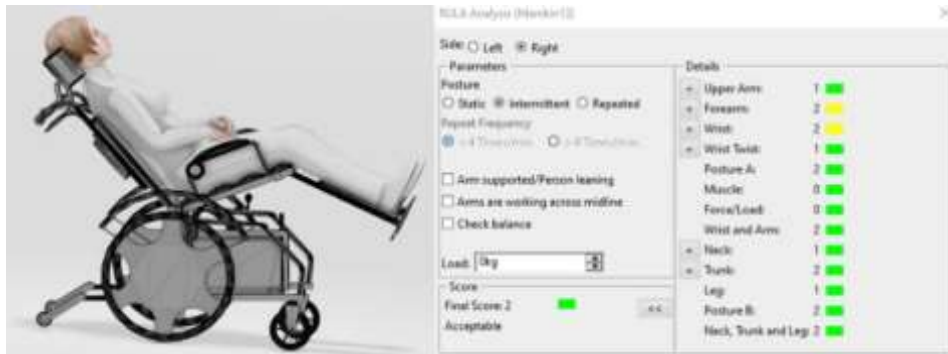
Figure 64 - Chair in position 25° T e 30° R

Source: Authors

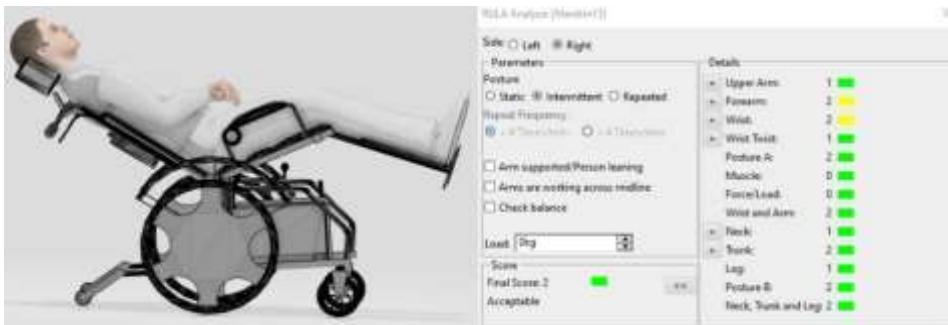Figure 65 - Chair in position 25° T e 40° R

Source: Authors

Figura 66 - Cadeira na posição 25° T e 40° R

Source: Authors

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

Source: Authors

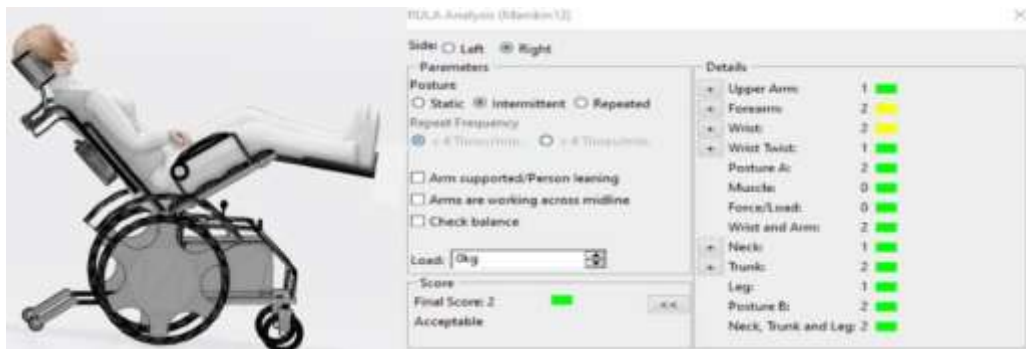Figure 68 - Chair in position 25° T e 55° R

Source: Authors

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

Source: Authors

Figura 70 - Cadeira na posição 35° T e 40° R

Source: Authors

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

Source: Authors

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

Source: Authors

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

Source: Authors

Figura 74 - Cadeira na posição 35° T e 65° R

Source: Authors

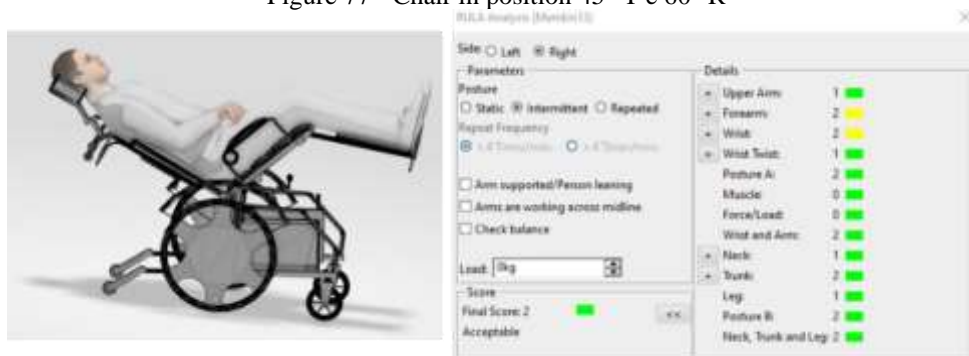Figure 75 - Chair in position 45° T e 50° R

Source: Authors
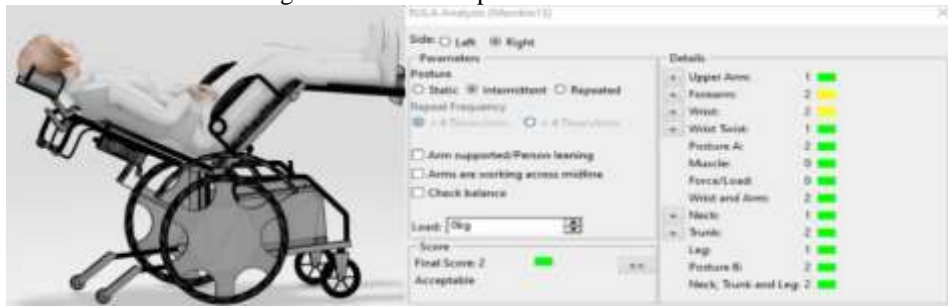
Figure 76 - Chair in position 45° T e 50° R

Source: Authors

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

Source: Authors

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

Source: Authors

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

Source: Authors

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

Source: Authors

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

Figure 81 shows the comparison between the conventional wheelchair and the designed wheelchair.

Figure 81 - Comparison of results: Conventional wheelchair vs. Designed wheelchair

Source: Authors

The greatest difference occurs in muscular activity because, due to the intermittence in activity, the impact on the muscles of the body is lower. This is possible due to potential changes in inclinations throughout the day, and as a result, the score goes from 1 in the conventional wheelchair to 0 in the designed wheelchair.

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

As a result, the ergonomic benefit was evidenced by changing the postural risk level from level 4 (Changes may be necessary) to level 2 (Acceptable posture)

CONCLUSIONS

Considering that the goal of the work was to propose an intervention and perform an ergonomic analysis on a Tilt-in-Space wheelchair, it can be concluded that, according to the RULA methodology, the conventional wheelchair shows ergonomic problems that can result in disorders, especially in the arms and legs region, as well as muscular difficulties due to excessive sitting.

Furthermore, the process of patient removal by the caregiver poses a high risk. As a first solution, the impact of making the wheelchair's armrest removable was analyzed to assist in patient removal by the caregiver. The application of the REBA methodology showed an ergonomic benefit, as the risk classification after making the armrest removable changed from "Very High Risk" to "Medium Risk."

After noting the increase in disabilities in Brazil and conducting immersion and ideation after interviews with the target audience, a product was developed to meet the needs of wheelchair users and their respective caregivers.

The analysis of the designed wheelchair shows physiological benefits, as when compared to the reference posture in the vertical position (sitting), all positions, except 15° backrest / 5° recline, result in a significant decrease in pressure and improvement in circulation, reducing health problems arising from prolonged sitting.

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

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