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Design Improvement of Manual Rigid Frame Wheelchair Based on Ergonomic Factors

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Abstract: This research focused on the redesign of manual rigid frame wheelchair based on ergonomics factors. Ergonomics is a research science that studies the relationships between humans and other system components and a profession that uses theory and design techniques to improve human well-being and overall system efficiency. Meanwhile, the wheelchair is an assistive device most commonly used by disabled persons for daily activities and mobility. To ensure the comfortability of the wheelchair and eliminate the risk of injuries, the wheelchair designs must typically accommodate a wide range of people ergonomically. The main objectives of this project were to propose an ergonomic manual rigid frame wheelchair and to examine the strength of the redesign manual rigid wheelchair by undergoing static study. Furthermore, the selection of material for the wheelchair also will be made to fulfil a sustainable and durable in the proposed design. Rapid Entire Body Assessment (REBA) was chosen as an ergonomic assessment tool to indicate the risk of musculoskeletal disorders (MSD) by analyzing it through Kinovea software. The REBA score of current manual rigid frame wheelchair design was 8 which indicated that this design was causing high level of MSD risk that further investigation and changes needed. Meanwhile, SOLIDWORKS software was used to propose the redesign and conducted the static simulation. The features like height-adjustable headrest, armrest and attachable leg rests were added to the proposed design. After inserting an ergonomic manikin into the proposed design through CATIA software, the REBA score implemented was 2 which indicated a low level of MSD risk. The REBA score was reduced by 75.00 % compared to the current design in the market. Carbon fibre was used as the material selected for the rigid frame. Through static simulation, the maximum stress value was 139.03 MPa was lower than the yield strength value which was 2263.00 MPa after a load of 2000 N was applied. This represented a significant and effective improvements had been made through this research.

Keywords: Posture Assessment, REBA, Ergonomics Product Design, SOLIDWORKS

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1. Introduction

According to World Health Organization (WHO), the wheelchair is a device that consists of wheeled mobility and seating posture support for those who are difficult to walk or move around [1]. Meanwhile, a manual wheelchair is propelled by the user or driven by someone else from behind. Therefore, the design of a manual wheelchair will affect a wide range of users from the aspects such as quality of mobility and comfortability of the wheelchair based on the upper and lower extremities.

Design is defined by either a plan or specification for the creation of an entity or structure. Generally, the design outcomes will be displayed in the form of either a prototype, product, or system [2]. Engineering design is a method of defining and solving a problem in the engineering field by developing the possible and suitable method or device to fulfil the desirable user's needs. According to International Ergonomics Association, ergonomics is a research science that studies the relationships between humans and other system components and a profession that uses theory and design techniques to improve human well-being and overall system efficiency [3]. Anthropometric data, the measurements of human body size and shape, which are the basis for all digital human models created [4], is used in ergonomics to decide the best scale, shape and type of product to bring more comfortable and more accessible use. In order to assess ergonomics design, a variety of assessment tools and software have been developed. An ergonomic assessment tool evaluates whole-body postural musculoskeletal disorder and risks using a systematic process when carrying out a task [5]. Rapid Entire Body Assessment (REBA) is one of the assessment tools for ergonomic design. REBA aims to create a whole-body postural analysis system that can detect musculoskeletal risks in different tasks [6]. It provides a quick and straightforward assessment of a human's whole body postural risk. The analysis can be done before and after the assessment to prove the injury risk is reduced after REBA implementation.

The wheelchair is perhaps the most common assistive device to improve mobility, especially for disabled people. Therefore, wheelchair designs must typically accommodate a wide range of people, each with their accessibility and body postural requirements, to ensure the comfortability of the wheelchair and eliminate the risk of injuries. On the other hand, a non-ergonomic wheelchair may cause pressure on the user's body and lead to health problems, especially to the spinal cord [7]. Therefore, this research study discussed the design of the existing manual rigid frame wheelchair, taking into account ergonomic factors, such as a more adapted to human body shape, allowing users to adjust the angle, better quality of wheelchair in term of strength and durability. The study attempts to mitigate users' uncomfortable experiences and safety risk by implementing new function and materials for the manual rigid wheelchair. Static analysis of the redesign manual rigid frame wheelchair is also being studied.

1.1 Significant of study

Stefanac et al. [8] stated that 90.40 % of wheelchair users had spinal cord injury, and 82.60 % of wheelchair users use manual wheelchairs. The highest dissatisfaction of wheelchair users who use a wheelchair for more than 5 years is the possibilities to adjust wheelchair parts which showed 23.10 %. Adjustable accessories like back support, head support and leg rest are required to ensure better mobility and comfortability. The second highest is 18.30 % which is not satisfied with the wheelchair comfort like the non-ergonomic wheelchair sits, which is slippery. Besides that, 16.30 % of the users are not satisfied with the dimension of a wheelchair from the aspects of size, width, depth and height. Therefore, it proved that the redesign of the wheelchair seat is needed by applying ergonomics factors and correct parameters.

2. Background

The background, also known as literature review, describes all the necessary information that is required to obtain the results of the study.

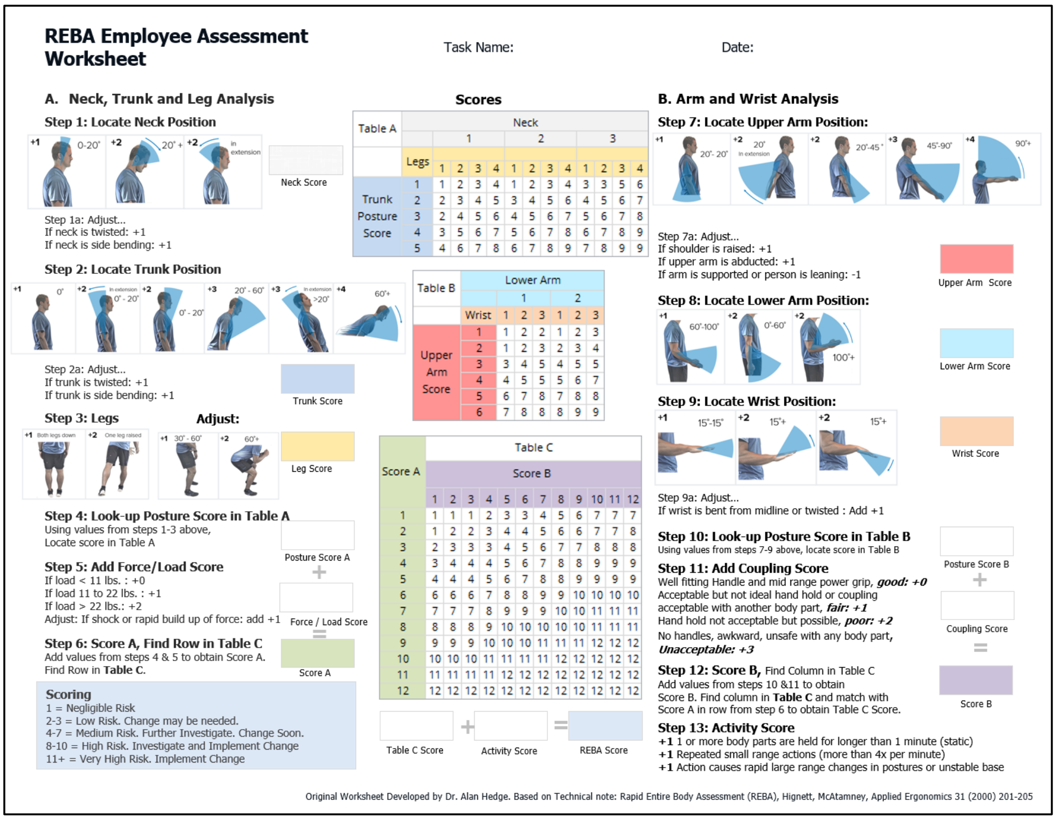
2.1 Ergonomics

Ergonomics is a scientific discipline that studies the relationships between humans and other system components that apply theory, concepts, data, and design methods to improve human well-being and the overall system's efficiency [9]. The goal of ergonomics is to eliminate the harms and risk of injury at workspace and work condition. It seeks to build clean, comfortable, and practical workspaces by considering human abilities and disabilities from aspects such as body size, power, skill, speed, and sensory abilities like vision and hearing. In addition, ergonomics aims to eliminate the injuries of soft body tissues and avoid musculoskeletal disorders (MSD). According to The National Institute for Occupational Safety and Health (NIOSH), MSD is the pain and injuries in joints, ligaments, muscles, nerves, tendons in the human musculoskeletal system, and structures that support the limbs, neck and back of humans [10]. Poor design of workstation or products will cause workers or users to become fatigued, frustrated, and injured.

2.2 Ergonomic assessment tool

An ergonomic assessment tool is a method that helps to determine the risk factor of work postural that may cause MSD. Therefore, an ergonomic assessment is also known as an ergonomic risk assessment. An ergonomic assessment aims to recognize and measure the risk factors to improve the workplace while creating a safer and less injury-prone workplace. There are many types of ergonomic assessment tool such as WISHA lifting calculator or NIOSH lifting Equation, Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment etc.

Rapid Entire Body Assessment (REBA) is an ergonomic assessment method that uses a systematic and effective way to classify the high risks posture for the whole body. REBA aims to develop a simple postural analysis framework responsive to musculoskeletal risk across a wide range of tasks, divide the body into parts, and assess each part separately using postures and movement planes. A simple and easy-to-use evaluation method was created through REBA to minimize the time, effort, and equipment. The main advantages of this method are the favorable cost-effectiveness and the most inconsistent ergonomic features that can be easily recognized based on the scoring of each part obtained after analyzing the whole parts of the body. As the final result of REBA, a single score that reflects the level of MSD risk is obtained which a scoring range is between 1 to 15, where the lowest score is 1, and the highest score is 15. Figure 1 is a single-page worksheet consisting of two parts: In part A, it consists of neck, trunk, and leg analysis. Meanwhile, part B consists of arm and wrist analysis. These parts A and B were designed to collect data for the five sections, which represented body posture adopted, the force used, type of movement or action, repetition, and coupling [11].



REBA Employee Assessment Worksheet

Task Name: Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 0-20° +2 20°+ +2 in extension

Neck Score

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 0° +2 in extension 0°-20° +2 0°-20° +3 20°-60° +3 in extension >20° +4 60°+

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs **Adjust:**

+1 Both legs down +2 One leg raised +1 30°-60° +2 60°+

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C.**

Score A

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C

Score A \ Score B	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 20°-20° +2 20° in extension +2 20°-45° +3 45°-90° +4 90°+

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

+1 60°-100° +2 0°-60° +2 100°+

Lower Arm Score

Step 9: Locate Wrist Position:

+1 15°-15° +2 15°+ +2 15°+

Wrist Score

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B

Step 11: Add Coupling Score
Well fitting Handle and mid range power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling
acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part,
Unacceptable: +3

Coupling Score

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain
Score B. Find column in **Table C** and match with
Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

Figure 1: REBA employee assessment worksheet [11]

2.3 Anthropometric measurements

Anthropometrics are quantitative body measurements that measure the population's range of body sizes [12]. It is used to evaluate the parameters of growth, development, and health of humans. For example, anthropometric measurements help determine if a child is growing normally at each age and specify whether someone's health and wellness are in danger according to the height or length, body weight, and head circumference [13]. Each population's anthropometric dimensions are classified by size and stated as percentiles. Commonly, the design range is between the 5th percentile (5th %) female to the 95th percentile (95th%) male. The smallest measurement for design in a population is usually the 5th % female value for a particular dimension. On the other hand, a 95th % male value may represent the largest dimension. Approximately 90.00 % of the population is accommodated in the 5th to 95th percentiles [12].

2.4 Finite Element Analysis (FEA) simulation

Finite element analysis (FEA) is the technique of analyzing the behavior of a part or assembly under specified conditions in order to examinate it by using the finite element method (FEM). FEA is a method of understanding and quantifying the impacts of a real-world circumstances on a component or assembly using mathematical models. Generally, engineers utilize FEA to simulate physical phenomena and eliminate the requirement for actual prototypes while also allowing for component optimization as part of the project design process. Engineers can use these simulations, which are run using specialized software, to predict the behavior of design part affected by physical effects such as mechanical vibration, fatigue, motion, fluid flow, mechanical stress, and heat transfer. Computer-aided design (CAD)/ computer-aided engineering (CAE) systems now have modules to perform the simulation, among the most commonly used software to carry out FEA simulation are SOLIDWORKS simulation, Autodesk, Ansys etc.

There are different types of FEA simulation by using SOLIDWORKS software. The most typical type of structural analysis performed with the FEM is static stress analysis. Static analysis is used to analyze the linear stress of components and assemblies that are loaded by static load. When the static analysis in SOLIDWORKS does not vary over time and the load remains constant, the body is said to be under static loading. If a body is subjected to static loading, under a variety of load circumstances, stress, stain and deformation of a component or assembly may be examined to ensure that costly failures are avoided during the design stage. In the end, the overall results are referred to as static analysis or static simulation.

3. Methodology

Methodology of this final year report had started by defining the problems faced by the user using a wheelchair. Based on the non-ergonomic wheelchair, several problems had been recorded where typically the material of the wheelchair frame was heavy. In addition to that, due to the non-adjustable accessories like head support and leg rests, it was not easy to fit the various body size of the user. It was also usually having a slippery wheelchair seat and back support. After that, the study's objectives and scopes had been determined to overcome the aforementioned problem. Then, the user's seating posture of the existing manual rigid wheelchair was then analyzed using REBA analysis through Kinovea software. Afterwards, it came to the brainstorming of the potential solutions to designing an ergonomic manual rigid wheelchair. Several factors were considered in this design, such as the need to have adjustable head support and leg rests, ergonomic wheelchair seat and back support, suitable measurement of the wheelchair based on an anthropometric study, solid and lightweight. The next step was to make an iteration design of the manual rigid wheelchair which was the process of product development to fix the problems of the existing manual rigid frame wheelchair. After creating the design chosen in SOLIDWORKS, CATIA was used to insert the ergonomic manikin into the proposed design so that REBA could be conducted using Kinovea. After REBA analysis was carried out, static analysis was conducted to analyze the new ergonomic manual rigid wheelchair design using SOLIDWORKS software.

3.1 Kinovea software

Kinovea 2D is a motion analysis software, which can determine kinematic parameters. It is a tool that can measure an item or person by recording video or taking an image and insert into the software. Examples of measurement that can be done using Kinovea software are measuring time span using chronometer function and measuring distance and angle by applying a function of line, angle, and goniometer instruments. Kinovea software provides valuable features such as observation, annotation, measurement, capture, and export. Therefore, it is essential to record a good video quality or take a clear image to get accurate and precise angle measurements for REBA analysis.

3.2 Rapid Entire Body Assessment (REBA)

REBA is an ergonomic assessment tool that employs a systematic approach to assess the upper body and lower body postural MSD and job-related risks. The needed or selected body postural, exertions of force, kind of movement or activity, repetition, and coupling are all evaluated using a single page worksheet. Accompanying discussions that further explain observations of the results are usually placed immediately below the results paragraph. In the REBA worksheet, there were two scoring sections: Section A and Section B. Section A covered the neck, trunk, and leg, while Section B covered the arm and wrist. Score Group A was conducted first before evaluating score Group B to ensure that any difficult or awkward postures of the neck, trunk, or legs that might affect the postures of the arms and wrist were covered in the assessment. After getting the REBA according to the worksheet, the level of MSD risk can be determined based on Table 1.

Table 1: Level of MSD risk based on REBA assessment tool [11]

Score	Level of MSD Risk
1	Negligible risk, no action required.
2 -3	Low-risk change may be needed.
4 – 7	Medium risk, further investigation, change soon.
8 – 10	High risk, investigate and implement change.
11+	Very high risk, implement change.

3.3 SOLIDWORKS software

SOLIDWORKS is a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) program developed by Dassault Systèmes. It is an engineering design software that can create 3-dimensional (3D) modelling design and commonly used by engineers and designers. It also comes with features like assembly drawing parts, creating drawing templates and simulation to study the modelling design. In this project, SOLIDWORKS was used as engineering software to create the proposed design of manual rigid frame wheelchair. After that, it was used to run the static analysis of the rigid wheelchair frame by defining different materials.

SOLIDWORKS simulation utilizes Finite Element Analysis (FEA) method to determine the behavior of components or assemblies when load is applied to it. The loads such as pressure, force, temperature, gravity, centrifugal or loads transported from previous simulation studies. The final result might be shown in the form of stress, displacement, or strain. In this project, SOLIDWORKS software will be used to design the 3D of an ergonomic manual rigid wheelchair. After that, the simulation will be done, covering the study of static.

3.4 CATIA software

Computer Aided Three-Dimensional Interactive Application, which is also commonly known as CATIA, is a widely used CAD tools from Dassault Systèmes. CATIA is a complete software package that includes computer aided-design (CAD), computer-aided engineering (CAE), and computer-aided manufacture (CAM). CATIA offers capabilities in a variety of field which includes part modeling, assembly modelling, surface modelling, Finite Element Analysis (FEA), and sheet metal part design. Besides, it also includes the function rendering which users are able to define material specification. In this project, CATIA software was used to insert ergonomic manikin into proposed design of manual rigid frame wheelchair before analyzing through Kinovea software. After the proposed design was created in SOLIDWORKS, the file was saved to .STEP file type.

4. Results

4.1 REBA analysis on current design of manual rigid frame wheelchair

Kinovea software was used to analyze and determine the user's body posture angles to the current design of manual rigid frame wheelchair according to the REBA worksheet. The data conducted was then analyze by using ergonomic assessment tool which was REBA to define the level of MSD risk on the current design of manual rigid frame wheelchair. Figure 2 showed the REBA analysis with the angle description of the body posture for group A which were (a) neck, (b) trunk, and (c) leg while for group B was showed in Figure 3 which were (d) upper arm, (e) lower arm, and (f) wrist.

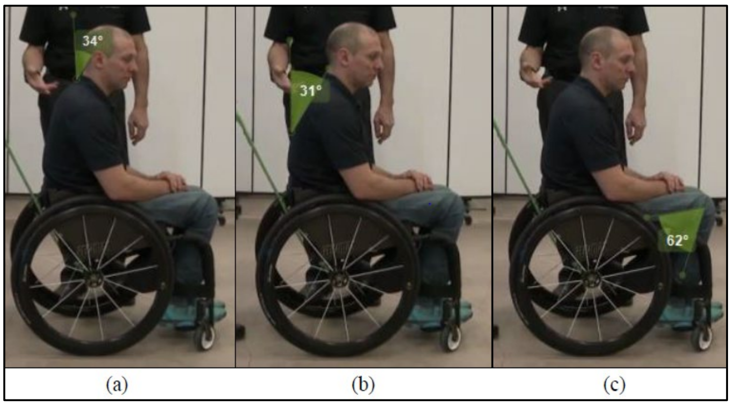


Figure 2: Neck, trunk, and leg REBA analysis for current design [14]

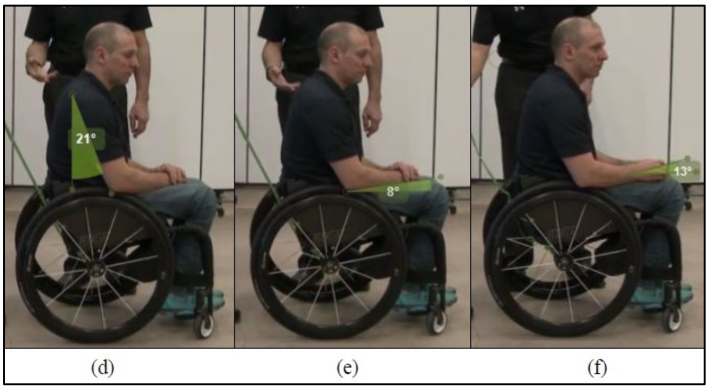


Figure 3: Upper and lower arm, and wrist REBA analysis for current design [14]

All the data analyzed were recorded in Table 2 below. After adding up the activity score, the total REBA score on current design of manual rigid frame wheelchair was 8. Since the total REBA score obtained was 8, the level of MSD risk of current design of manual rigid frame wheelchair was in high risk and should be investigated and implemented changes to the non-ergonomic design.

Table 2: REBA score on current design of manual rigid frame wheelchair

Body position	Score
Neck	2
Truck	3
Legs	3
Score in Table A	7
Force/Load analysis	0
Score for Group A (Score in Table A + Force/Load analysis)	7
Upper arm	2
Lower arm	2
Wrist	1
Score in Table B	2
Coupling analysis	0
Score for Group B (Score in Table B + Coupling analysis)	2
Score in Table C	7
Activity score	1
Total REBA score (Score in Table C + Activity score)	8

4.2 Proposed design

By referring to the REBA score on current design of manual rigid wheelchair in Table 2 and, also the survey conducted by Stefanac et al., a new design of manual rigid frame wheelchair was proposed as illustrated in Figure 4 below. The area of the proposed design was 1131mm x 1332 mm. The design of the present manual rigid frame wheelchair was altered by modifying the ergonomics dimensions according to the common anthropometric measurement for seated position and the 5th to 95th % values for both males and females in seated. Various beneficial features were added to the proposed design like adjustable headrest, armrest, and leg rests. Changing of materials of the wheelchair frame also being considered in the new design of manual rigid wheelchair.

Figure 4: Proposed manual rigid frame wheelchair design

4.2.1 Redesign backrest

According to the current design of backrest, the back of user was not supported. This might lead to a significant impact on variety of health issues especially to the spinal cord. Figure 5 showed the redesign of ergonomic backrest from orthographic view and side view. The development of ergonomic backrest helped user to support the spine's natural curve, and its ergonomic contour shape suited and hugged the user's back perfectly, acting as a posture corrector.

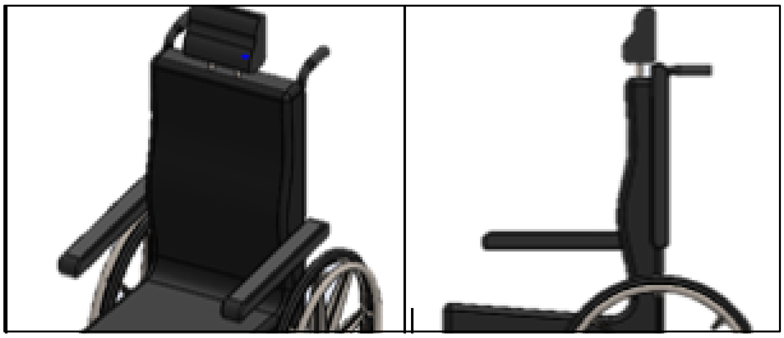


Figure 5: Redesign of backrest

4.2.2 Redesign seat

Figure 6 illustrated the redesign of seat according to ergonomic factor. According to the anthropometric measurements, the ideal seat length was between 429mm to 536mm while the ideal width of the seat was 368mm to 437mm. Thus, the area of seat was designed with a length of 478mm and a width of 422mm. A more extended seat depth could spread the weight out over the thighs; therefore, the pressure was not only focused on the user's back and buttock, but it also lowered the chance of getting pressure sores. Besides, the end of the seat was designed slightly higher in order to prevent slippery.

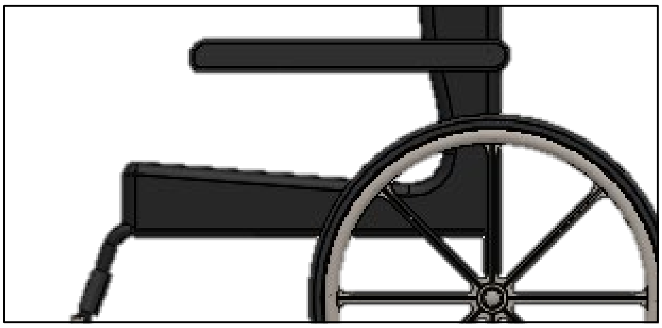


Figure 6: Redesign of seat

4.2.3 Height adjustable headrest

Figure 7 showed the design of the adjustable headrest. The area of the adjustable headrest was 150mm x 200mm. The curve of the headrest was designed to support the suboccipital area of the user. Users were able to adjust the height of headrest according to their head position, and also the headrest was removable when it was not in used.

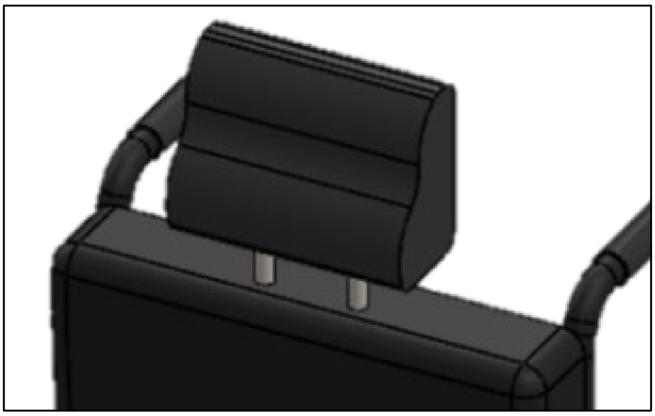


Figure 7: Adjustable headrest design

4.2.4 Adjustable armrest

Figure 8 illustrated the feature of adjustable armrest on the proposed manual rigid frame wheelchair design. The design of armrest feature was necessary in order to support the arm of users to prevent shoulder and back pain when seating on the wheelchair. In addition, the armrest could be adjusted as shown in Figure 8 when it was not in used. This feature eased the movement of users when moving to other places from the wheelchair.

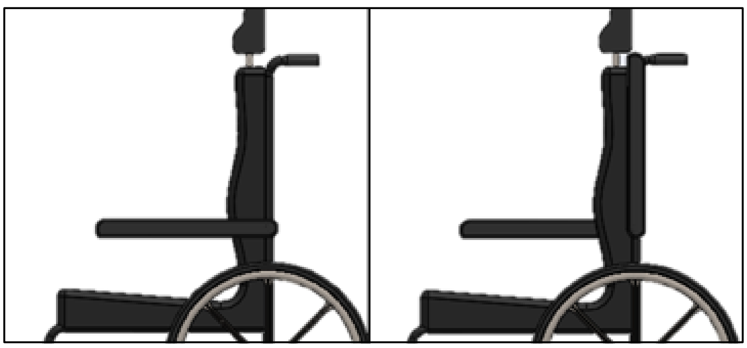


Figure 8: Adjustable armrest

4.2.5 Adjustable leg rests

The design of adjustable leg rest of the manual rigid frame wheelchair was shown in Figure 9 below. The position of leg rest was adjustable according to the length of user's leg, and there was a design of calf strap added to support their legs, therefore ensured the comfort of wheelchair users. Also, same reason as the design of adjustable armrest, the leg rest could be removed to ease the movement of users.

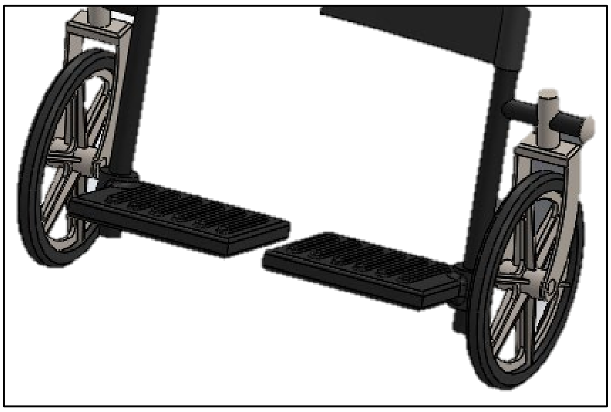


Figure 9: Adjustable leg rest design

4.3 REBA analysis on proposed design of manual rigid frame wheelchair

After applying the virtual ergonomic manikin in the proposed design of manual rigid frame wheelchair by using CATIA software, Kinovea software was used to analyze and determine the user's body posture angles to the proposed design of manual rigid frame wheelchair according to the REBA worksheet. The data conducted was then analyzed by using ergonomic assessment tool which was REBA to define the level of MSD risk on the proposed design of manual rigid frame wheelchair. Figure 10 showed the REBA analysis for proposed design with the angle description of the body posture for group A which were (a) neck, (b) trunk, and (c) leg while for group B was showed in Figure 11 which were (d) upper arm, (e) lower arm, and (f) wrist.

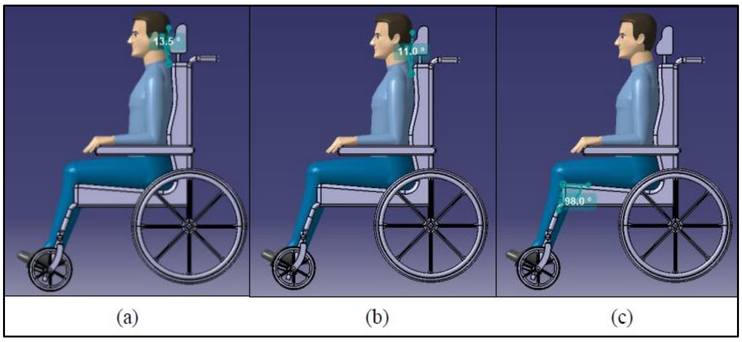


Figure 10: Neck, trunk, and legs REBA analysis for proposed design

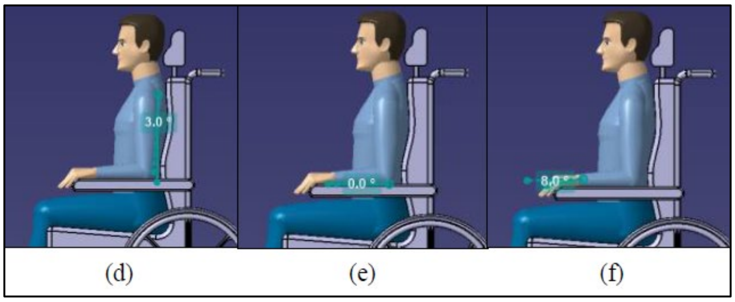


Figure 11: Upper and lower arm, and wrist REBA analysis for proposed design

Table 3 précised the total REBA score on the proposed design of manual rigid frame wheelchair. After inserting an ergonomic manikin into the proposed design, the data was analyzed and recorded based on REBA worksheet. The total REBA score for the proposed design was 2. This result showed that the proposed design was in low level of MSD risk, therefore caused less injuries to user's health.

Table 3: REBA score on proposed design of manual rigid frame wheelchair

Body position	Score
Neck	1
Truck	1
Legs	2
Score in Table A	2
Force/Load analysis	0
Score for Group A (Score in Table A + Force/Load analysis)	2
Upper arm	1
Lower arm	1
Wrist	1
Score in Table B	1
Coupling analysis	0
Score for Group B (Score in Table B + Coupling analysis)	1
Score in Table C	1
Activity score	1
Total REBA score (Score in Table C + Activity score)	2

4.4 Comparison between current design and proposed design

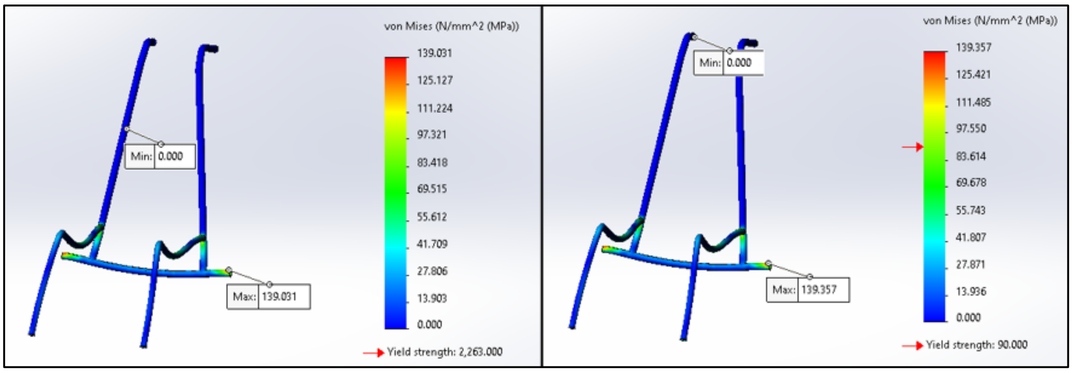
Table 4: Comparison of REBA scores between current and proposed design

Manual rigid frame wheelchair design	Current design	Proposed design	Percentage improved
Score for Group A (Score in Table A + Force/Load analysis)	7	2	71.43%
Score for Group B (Score in Table B + Coupling analysis)	2	1	50.00%
Total REBA score (Score in Table C + Activity score)	8	2	75.00%

There was a huge different between the REBA scores for the design of manual rigid frame wheelchair in the current market and the proposed design by referring to Table 4 which the percentage improved was calculated. The score for Group A of current manual rigid frame wheelchair design was 7. The non-ergonomic design of backrest and seat rest, lack of headrest and also non-adjustable leg rest had all been identified as contributing factors to the high REBA score. The high REBA score indicating that it was in medium risk and further investigation was required. In the proposed design of ergonomic manual rigid frame wheelchair, the REBA score for Group A was reduced to only 2. This means that the proposed design had improved by 71.43 % which was more ergonomic to the wheelchair users. Meanwhile, the score for Group B of current manual rigid frame wheelchair was found 2 and reduced to 1 in the proposed design. The score for Group B was reduced by 50.00 %. The total REBA score for the current design was 8 which was at high level of MSD risk, indicating that it required investigation and implement changes. In response to these issues, wheelchair users were more likely to adopt poor posture and feel uncomfortable when using the manual rigid frame wheelchair. The proposed design received a REBA score of 2, which indicated a low level of MSD risk. The total REBA score had been lowered for 75.00 % which resulting a huge decrease of MSD risk to the wheelchair users. This represented a significant improvement over the REBA score of the existing design.

4.5 Static study on the rigid frame after changing material

The rigid frame was the main body of the wheelchair, and it could not be replaced once manufactured, therefore the material of the frame must be able to prevent damage and rust. There were two materials considered to manufacture the rigid frame of the wheelchair which were carbon fibre and aluminium. Figure 12 showed the static analysis of proposed design of rigid frame when a load of 2000 N applied to it by using different material which were (a) carbon fibre and (b) aluminium.



(a) (b)

Figure 12: Static analysis of proposed design of rigid frame

Table 5: Comparison of FEA results between material used for rigid frame

	Carbon fibre	Aluminium
Maximum stress value (MPa)	139.03	139.36
Yield strength (MPa)	2263.00	90.00
Mass value (kg)	3.0064	4.5603
Volume (m^3)	0.0017	0.0017

According to Table 5 above, the maximum stress value when carbon fibre was used as the material for the rigid frame was 139.03 MPa which was lower than its yield strength, 2263.00 MPa. This showed that when carbon fibre was applied as material to the wheelchair frame, it was able to support the load of 2000N. On the other hand, the maximum stress value when aluminium was used as the material for the rigid frame was 139.36 MPa which was greater than its yield strength, 90.00MPa. This meant that the rigid frame of wheelchair was failed to support the 2000N of load when aluminium was used. Other than this, the mass value of the rigid frame when carbon fibre was applied was 3.0064 kg, which was lighter than when using aluminium with the mass value of 4.5603 kg. Therefore, carbon fibre was chosen as the material for the rigid frame of the wheelchair in this project.

5. Conclusion

In conclusion, all the objectives of this project had been successfully achieved. After measuring the current design of manual rigid frame wheelchair through Kinovea software, REBA worksheet was used to analyze each body parts of the user and the final REBA score was 8. This showed that the current design might cause high level of MSD risk to the wheelchair users. Therefore, further investigation and changes was implemented. In the proposed design of manual rigid frame wheelchair, improvements like ergonomic backrest and seat were designed to give the best body postural support and prevent slippery. Besides, a height-adjustable headrest, armrest, and leg rests were added to the wheelchair. The proposed design was proposed by using SOLIDWORKS software and all the ergonomic dimensions were according to the anthropometric measurements in the seated position. After analyzing the proposed design with ergonomic manikin, the REBA score was only 2 which indicated a low level of MSD risk. By comparing the current and proposed design, the total REBA score of the proposed design was reduced for 75.00 % which represented a significant and effective improvements had been made and achieved the objective of the project. In addition, the static study simulation was accomplished by using SOLIDWORKS software. After applying carbon fibre as the material, a total load of 2000 N (≈200 kg) was applied to the rigid frame of the wheelchair. After running the simulation, the maximum stress value was 139.03 MPa and the yield strength value was 2263.00 MPa. Since the maximum stress value is lower than the yield strength value, the strength of proposed design of manual rigid frame wheelchair was strong enough to overcome a load of 2000 N. This result proved that the second objectives was achieved.

There are some useful recommendations that could be used to enhance future research regarding to the related topic. First, future research is recommended to manufacture the proposed design based on the results of this study. It is recommended to manufacture the product according to the proposed design and its measurements in order to carry out the REBA assessment directly to the real product. Next, the future research is also recommended to enlarge the scopes of this study by adding the cost analysis based on the proposed design. The purpose of doing cost analysis is to produce a manual rigid frame wheelchair which provide more details and produce an affordable ergonomic wheelchair for the users. In addition, in future research, the manual rigid frame wheelchair can be analyzed and evaluated in other ergonomic assessment tools such as Rapid Upper Limb Assessment (RULA). By comparing the results from RULA and REBA which was used in this study, a more accurate and reliable results can be conducted.

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