ORIGINAL ARTICLE

DESIGN IMPROVEMENT OF AUDITORIUM SEATING: A CASE STUDY AT PAGOH EDUCATION HUB

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ABSTRACT

This study is concerned about the auditorium seating design based on the ergonomics concept. Ergonomics is the science of fitting the product to its users or fitting the job to the worker. This study is carried out at Pagoh Education Hub Shared Facility Auditorium. The main objective of this study is to assess the ergonomics posture of users using auditorium's seating. The poor design of furniture may be possibly cause incorrect posture which will further lead to health problems such as back pain and spinal distortion. The Kinovea software is utilized to measure the posture. Each measurement of different body part posture is assessed by using Rapid Entire Body Assessment (REBA) in order to indicate the risk level of the auditorium's seating. The REBA score of the existing auditorium's seating is 7 indicating medium risk which requires further study for improvement. The second objective of this study is to redesign the auditorium's seating based on the ergonomics concept. The proposed design of auditorium's seating uses SolidWorks software by referring to the guideline from the Department of Occupational Safety and Health, Ministry of Human Resources Malaysia (DOSH). The desired features such as headrest and armrest are added to the proposed design. The REBA score of the proposed seat design is 3 which indicate significant improvement compared to REBA score of the current design, in terms of ergonomics factors.

Keywords: *Posture Assessment, REBA, Ergonomics Product Design, SolidWorks*

INTRODUCTION

Design is a significant step in manufacturing process in order to yield a creation or provide an outline about appearance or function of a specific product. Design is a phase of the product development process that gives significant impact on the opportunities and limitations of the next phase, since the developed product geometry will influence the manufacturing, assembly, maintenance, user experiences and so forth. Design also directly influences the marketing sector and cost excessively when the demand for a particular product design is low. Approximately 40% of all issues with product quality are due to poor design. Nowadays, ergonomics design is one of the most concerned design concepts and therefore, is preferred by the society. Ergonomics design is the ergonomics concept addressed in specific designs. Generally, the concept of ergonomics is to fit the product or task to the individual or user instead of fitting the individual or user to the task or product. Ergonomics is applied in product design field by taking user characteristics into account in order to ensure the excellent fit between the users and the products they interact with. The role of ergonomics concept in product development is amplified, it can ensure the product or environment is safe. The ergonomics design can be assessed using variety of developed assessment tools and software. Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) are assessment tools which are able to evaluate and analyse the human body posture. RULA is developed to investigate ergonomics-related upper limb disorders and the REBA is implemented to carry out the postural analysis which is focused on the musculoskeletal risks caused by bad posture. Thus, this study is aimed at assessing the ergonomics posture of users of auditorium seating, then redesigning the seating for improvement in ergonomics context. By considering the ergonomics features to the design, it is expected to lower the REBA score indicating lower risk to the users.

LITERATURE REVIEW

Ergonomics is the science of work which encompasses the people who do it and the ways it is done, of the tools and equipment they use, the places they work in, and the psychosocial aspects of the working situation. The goal is to obtain the best match in the framework of the task to be completed between the product being designed and its users. In others words, the philosophy of ergonomics is to match the job to the worker and the product to the user. Some of the occupations in the industry are exposed to the lower back pain and neck pain which include the work activities such as repeating the same motion throughout the workday, working in extreme temperature, using excessive force to perform tasks, working in awkward positions, lifting heavy items or being exposed to excessive vibration.

Ergonomics Product Design

In engineering design, ergonomics is a product development that deals with user interactions and

other process components, and a discipline that implements theory, concepts, information and methods to improve its well-being and overall system performance. To obtain an ergonomics design, human characteristic such as height, weight, as well as information on human hearing, vision and other characteristics are taken into consideration.

Ergonomics Assessment Tool

Ergonomics assessment tool is used to evaluate the work posture associated with ergonomics risk factor and corresponding approach will be designed based on the level of Musculoskeletal Disorders risk. REBA is common and user-friendly ergonomics tool. Both of the ergonomics assessment tools are easy to use without any expensive apparatus and equipment required. It is carried out by using a specific designed worksheet. The worksheet of the REBA is shown in Appendix A. There are some studies carried out to differentiate between REBA and RULA.

REBA is an ergonomics assessment tool focused on whole body evaluation and most suitable for both static and dynamic works. There are five levels of actions to indicate the obtained scores. REBA has been enhanced in the implication of RULA's neutral positions and leg positions. While RULA interprets the neutral position of the wrist, neck and trunk with 0° of the corresponding joint motion angle and altering leg positions are categorized into only two balanced and unbalanced classes. REBA defines the neutral position as positions to a certain angular distances of the connected joints and classifies leg positions into four classes.

The purposes of the development of REBA include designing a postural analysis system sensitive to musculoskeletal risks occurring in different jobs, classifying the body into different parts in order to be assessed individually based on a posture guideline, developing a systematic scoring system for muscle activity regarding static, dynamic, rapid change or unstable postures, related to coupling while handling of loads and developing a indication of risk revel associated with relevant actions.

Spine

Spine (vertebral column or backbone) is a column consisting of 26 bones when reaching adulthood. It can be separated into two which are 24 moveable separate vertebrae interspaced with cartilage and additionally the fused sacrum and coccyx. Figure 1 shows the spine which looks like a natural S shape when viewed from the side which enables it to withstand the body's weight and maintain the balance of the body. Basically, the practice of correct posture of standing, walking, sitting and lying downs are the best ways to protect the spine in order to reduce the unnecessary amount of strain on the spine during movement. The function of the spine is to provide structural support and balance to maintain an upright posture. Besides that, spine acts as a shelter in order to protect the spinal cord, nerve roots and the body's internal organs. It also enables flexible motion.

Appropriate posture while walking, sitting and lying down will influence the spine; therefore the lumbar support concept was developed and introduced to overcome the problem. Lumbar support is the one of the most common ergonomics props that can be implemented on the seat design. Figure 1 illustrates how the lumbar support tool supports the human spine.

Figure 1: Lumbar support demonstration
Source: Best Exercises for Lower Back Pain (2019)

While sitting, the natural curve inward of lumbar vertebrae of spine is unable to fit the backrest and a gap is formed between the spine and the backrest. Therefore, it tends to form unnecessary stress on the spine. The chair designed with lumbar support manages to promote correct posture by filling the gap between the lumbar spine and the seat.

Chair Design

Seating posture is one of the highest risk factors towards the body. Therefore, an appropriate chair design is significant in order to offer support for the back, legs, arms and buttocks. The standard and guideline of chair design specification pertaining ergonomics purpose have been developed by related government and private agencies like the Department of Occupational Safety and Health Ministry of Human Resources Malaysia (DOSH). According to the DOSH guideline, the ideal chair design dimension is as shown in Figures 2 and 3 respectively.

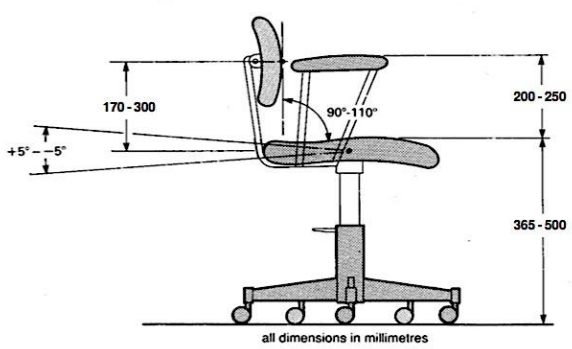


Figure 2: Recommended chair design dimension (side view and front view)

Source: (DOSH, 2002)

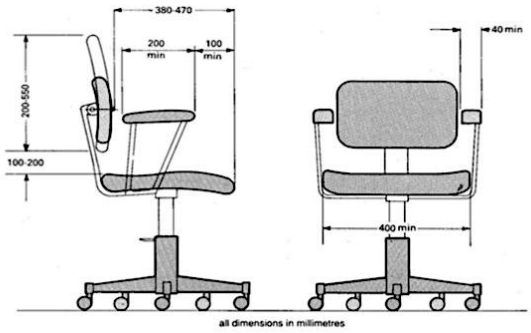


Figure 3: Recommended chair design dimension (side view and front view)
Source: (DOSH, 2002)

The appropriate design of backrest gives support to the natural S-shape curvature of human's spine and practices adequate seating posture. The poor back support is unable to provide lumbar support and leads to back-pain and fatigue. It is necessary to provide some space for the buttocks by leaving a gap between seat and the backrest.

A seat may be suitable for the average height of users. However, it may be an uncomfortable seating posture for tall or short users. Therefore, the adjustable seat height plays a major role in order to fit wide range of user's heights. Referring to Figures 4(a), 4(b) and 4(c), the adjustable seat should be adjusted at suitable height based on user's height in order to obtain the adequate footrest. In addition, the seat pan of the seat must be large enough to fit various users' nip size and should be designed as adjustable seat pan to support differences in seat posture.

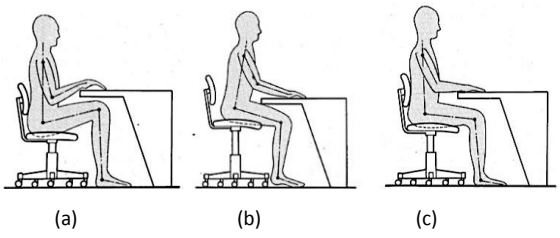


Figure 4: The height of seat

By referring to Figure 5, when an armrest is designed too high or too low, it will lead to awkward posture and causes the upper limb to experience unnecessary tension. The armrest should be designed for user's arm to be able to naturally rest on the armrest without forming any awkward posture.

Figure 5: Shoulder posture caused by difference height of armrest
Source: (Peterson, 2019)

METHODOLOGY

This study comprises of two major processes which are designing the specific product and conducting evaluation and analysis on the product. The relevant data and information is gained from the users by implementing survey methodology. In this study, REBA is used to assess user's seating posture when sitting on the auditorium's seat. As for improvement, the propose of chair design is based on theoretical ergonomics design. In future, the fabricated design will be assesses for obtaining the real data for REBA analysis.

Survey Methodology
Survey is employed in this study as a methodology to collect significant data and information from entities for the purposes of constructing quantitative descriptors of the attributes of the specific population of which the entities are members. This is an effective approach to communicate with respondents.

The overall sample size of this survey is 200 sets. In this study, paper-based survey is implemented instead of online survey. The population of this survey is targeted at Pagoh Education Hub and the target respondents are the users of Shared Facilities Auditorium. Since the population of the survey distribution is limited, paper-based research becomes vital in order to gather accurate data and information from the appropriate target population.

Most of the questions stated in this questionnaire are related to auditorium ergonomics seat design. This is to investigate the precise opinion about the factors causing discomfort condition when using the auditorium and the demand feature of the ergonomics design from the auditorium users. This approach is able to ease the design process.

The demographic data stated in the questionnaire involve gender, occupation, workplace, heightweight, frequency use of the auditorium and the purpose of using the auditorium. The characteristic of the respondents such as height and weight are the main considerations in the design process in order to design a user-centered product.

In addition, a pilot survey is carried out in this study. Pilot test is conducted to test a smaller amount of sample size in order to make sure the questionnaire is suitable to be answered by the specific population. Pilot test allows researchers to investigate any potential problems. The questionnaires can be modified and improved if the pilot test fails to generate the result.

Kinovea Software

Kinovea software is developed by Joan Charmant in 2004. Kinovea software is effective analysis software which is used to analyse physical movement of corresponding video by providing the accurate measurement and annotation. In this study, the accurate and precise measurement of user's posture plays an important role in order to solve the ergonomics assessment task.

Rapid Entire Body Assessment (REBA)

REBA was developed by Hignett and McAtamney (2000). It is an effective and user-friendly ergonomics assessment tool focusing on the whole body postural musculoskeletal disorders. This assessment tool is useful especially to indicate the user's leg position when seating on the designed ergonomics seat as well. Each of the body part is given the score according to the guideline which can be referred to in the REBA worksheet attached in Appendix A. Table 1 shows the guideline of overall REBA scoring.

Table 1: The guideline of overall REBA scoring

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
More than 11	Very high risk, implement change now

Solidworks Software

Solidworks software is a well-known engineering design software and widely used by engineers and designers. Solidwork software acts as a solid modelling CAD and computer-aided engineering (CAE) program that is widely used to generate three-dimensional (3D) modelling design. This software is developed by Dassault Systems in 1995. Solidwork software with advanced features can be used to design an assembly part, analyse a model with different parameters, simulate a design part based on different conditions and so forth. In this study, Solidwork software is extensively implemented in the design process to sketch the design of auditorium ergonomics seat with appropriate dimensions in 3D. Furthermore, the designed ergonomics seat is prepared for analysis and simulation by using Solidwork software regarding to the average user's height and weight.

DATA ANALYSIS AND RESULT

Analysis of Survey

Figure 6 shows the overall analysis regarding to the user's experience of auditorium seat. It can be seen that majority of users face difficulty when utilizing the auditorium's seat. This data proves that it is necessary to redesign an auditorium's seat based on the ergonomics concept.

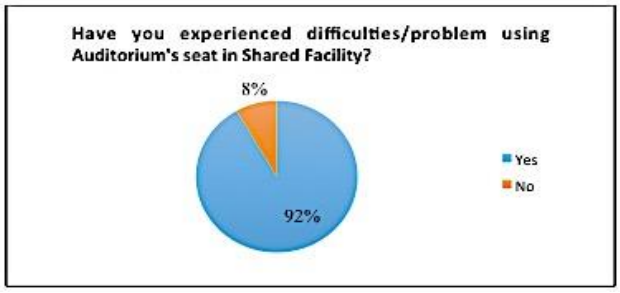


Figure 6: User's experience of auditorium seat

Figure 7 highlights the overall data regarding the factors causing discomfort when sitting on the auditorium's seat. 30% accounts for non-adjustable seat height and 25% of users were unsatisfied with the fixed chair design. Other factors of uncomfortable experience included distance between the chair and desk, arm rest and head rest.

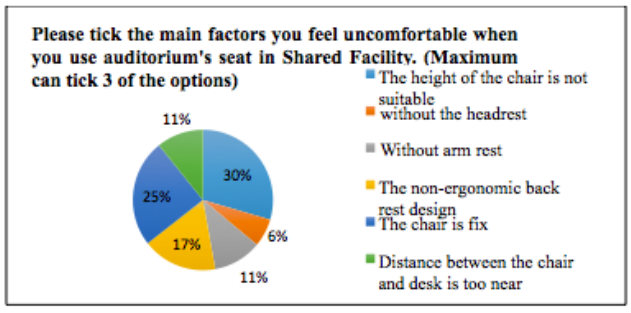


Figure 7: Analysis of uncomfortable factor

Figure 8 shows that the analysis of desired seat features. Majority responders desired adjustable seat height and lumbar support backrest. The rest of the desired seat features included armrest, headrest and backrest tilt adjustment. Some of the responders suggested cushion seat in order to provide a comfortable seating experience.

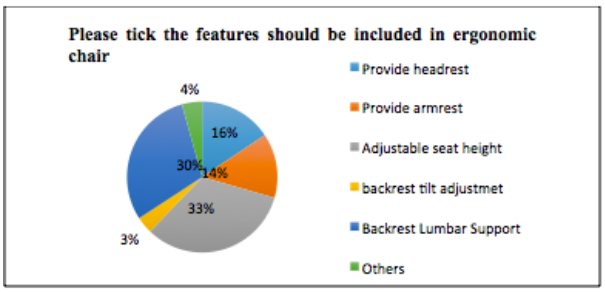


Figure 8: Analysis of desired seat feature

Analysis of Seating Posture and REBA Score on Current Auditorium Seating

The analysis of the current auditorium's user posture is accomplished by REBA where the analysis focused on the effect of the seat design on user's posture. In addition, Kinovea software is used to measure the user's corresponding posture angle. Figure 9 shows the analysis of REBA with the angle description of the body posture for neck (a), trunk (b) and leg (c). Table 2 shows the analysis of REBA assessment for neck, trunk and leg part.

(a) (b) (c)

Figure 9: Neck, trunk and leg analysis for REBA

Table 2: REBA scoring for neck, trunk and leg part

Description	Analysis	Score
Neck position is flexion for 59°	Neck Position	+2
Trunk position is flexion for 12°	Trunk Position	+2
Legs position is bending for 60°	Leg Position	+2

Table 3 summaries the overall REBA score based on the analysis of different body parts positions. Each of the body part position's score is obtained according to the REBA assessment worksheet. From Table 3, it can be summarized that the overall REBA score is 7. Since the obtained REBA score of current auditorium's seat design is 7, so the level of MSD is on medium risk which requires further investigation and urgent changes.

Table 3: REBA score of current auditorium's seat design

Body Part	Score
Neck	2
Trunk	3
Legs	3
Posture Score A (Table A)	6
Force/ Load Score	0
Score A (Posture Score A+ Force/ Load score)	6
Upper Arm	2
Lower Arm	1
Wrist Position	1
Posture Score B (Table B)	1
Coupling Score	0
Score B (Posture Score B + Coupling Score)	1
Acticity Score	1
Table C Score	6
REBA Score (Table C score + Acitivity Score)	7

Proposed Design

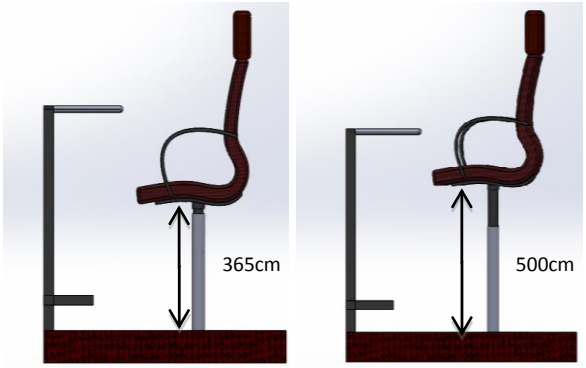
The selected auditorium can fit a maximum of 250 audiences. The overall area for an auditorium seat is 980mm x 600mm. This dimension does not undergo any changes. Figure 10 illustrates the proposed auditorium seat design. The proposed auditorium seat design is done by referring to the outcome of REBA on the existing auditorium seat design and the results from the survey. The existing auditorium's seat design is modified by changing the ergonomics dimension and adding several useful features. The features included adjustable seat height, armrest, headrest and footrest.

Figure 10: Proposed auditorium seat design

Adjusted Seat Height

As mentioned earlier, a chair with fixed seat height is unable to fit a wide range of user's body height. An adjustable seat height is the main

demand of an ergonomics chair. Figure 11(a) shows the adjustable seat height at lowest height, while Figure 11(b) illustrates the adjustable seat height at highest height. According to the Department of Occupational Safety and Health Ministry of Human Resources Malaysia (DOSH), the ideal adjustable seat height is designed in the range of 365mm to 500mm. The users can adjust the seat height based on their respective body height.



(a) (b)

Figure 11: The adjustable seat height

Redesign Backrest

Referring to the existing seat design, the seat is designed with lumbar support backrest. Unfortunately, majority of the users experienced uncomfortable seating experience caused by the original backrest design. Figure 16 shows the current backrest design. It can be figured out that the lumbar support backrest of the existing auditorium seat is designed 30cm from the seat pan. The backrest accounts for one of the redesign purposes. Figure 12 shows the modified backrest design. The backrest design of the proposed design is located at 20cm from the compressed seat pan. This can fully support human's inward part of the spine.

***Figure 12**: Redesign of backrest*

Movable Seat Position

Figure 13 illustrates the proposed seat design with movable seat position (maximum forward movement), while Figure 19 shows the maximum backward movement of the movable seat position. One of the ergonomics seat features is movable seat position. Due to the limited seating area in the auditorium, designing an all axis movable seat is impossible. Only seats that are designed to be movable in y-axis direction is possible due to the limited space.

Movable seat position can overcome the narrow distance between the chair and table. Users can adjust the seat position. Due to the limited platform width, the movable pathway is designed in a distance of 20cm.

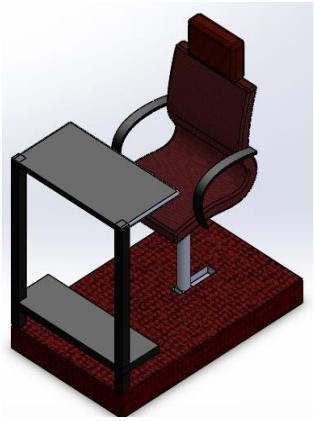


Figure 13: Movable seat position (Maximum forward movement)

Armrest

Figure 14 illustrates the armrest feature designed on the proposed seat design. Seating posture without any arm support will lead to unnecessary load on the neck, shoulder and back. Armrest with appropriate dimensions is able to minimize the stress and muscle loads on shoulders and arms. The armrest is designed with the dimension of 180mm x 260mm.

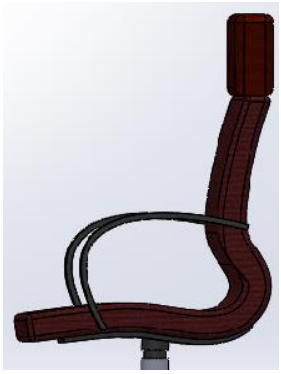


Figure 14: Armrest design

Headrest

Figure 15 shows the headrest designed with the dimension of 250mm x 150mm. Headrest features are able to provide neck and head support. Therefore, neck strain and tension in the shoulder and upper trunk can be reduced significantly.

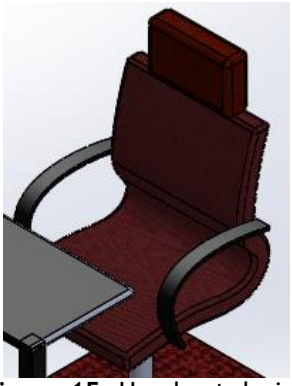


Figure 15: Headrest design

Footrest

Figure 16 shows the table design associated with footrest design. Footrest manages to practice correct seating posture. When the foot is not resting on the floor, it will cause extra tension on the back of legs. Based on this problem, footrest is able to overcome the extra tension by providing support for foot. The footrest is designed 8cm away from the floor. The redesign is focused on the design of auditorium seat and table as well. Appendix B illustrates the orthographic drawing of proposed auditorium seating design with dimension notation (seat).

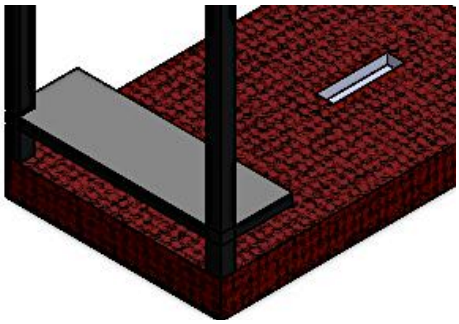


Figure 16: Headrest design

REBA Score on Proposed Auditorium Seat

Table 4 summaries the overall REBA score on proposed auditorium seat design based on the analysis of different body part positions. Each of the body part position's score is obtained according to the REBA assessment worksheet. From Table 4, the overall REBA score for proposed auditorium seat is 3, which indicates MSD at low risk level.

Table 4: REBA score of current auditorium's seat design

Body Part	Score
Neck	2
Trunk	2
Legs	1
Posture Score A (Table A)	3
Force/ Load score	0
Score A (Posture Score A+ Force/ Load score)	3
Upper Arm	1
Lower Arm	1
Wrist Position	1
Posture Score B (Table B)	1
Coupling Score	0
Score B (Posture Score B + Coupling Score)	1
Activity Score	1
Table C Score	2
REBA Score (Table C Score + Activity Score)	**3**

Comparison between Current Design and Proposed Design

The major comparison that can be observed is the REBA score of current auditorium's seat design and proposed auditorium's seat design. Initially, the REBA score for current design reached 7 which is located at the upper boundary of medium risk which indicates the need for further investigation and urgent change. The problem that causes the high REBA score has been investigated and it was found that fixed seat height, fixed seat position, poor backrest design, absence of armrest and headrest are the main causes of discomfort. Regarding to these problems, users tend to practice incorrect posture and feel uncomfortable when sitting on the auditorium seat.

To enhance the seating experience, the significant features are created in the proposed design. Solidwork software is utilized to create a new design. The REBA score obtained by the proposed design is 3 which can be considered as low risk level. This shows a major improvement compared to the REBA score of the current design.

CONCLUSION

In conclusion, the objectives of this study have been successfully achieved. The current auditorium seating design is analyzed by using REBA assessment. The corresponding REBA score achieved by existing auditorium's seating is 7 which indicate medium risk level that requires further investigation and improvement. From the assessment, it shows that the main problems that led to high REBA score included inappropriate backrest design, fixed seat height and fixed seat position. All of these problems cause erroneous seating posture. The auditorium's seating is redesigned by using Solidworks. From the analysis and result of paper-based survey, majority of the respondents desire for adjustable seat height, headrest design, armrest and backrest lumbar support. The ergonomics measurement of the redesigned chair is based on the guideline of DOSH. After the redesign of auditorium seating is complete, the REBA score is successfully reduced to 3 which indicated low risk that lesser change might be needed. This shows the significant improvement of seating posture.

Acknowledgements

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REFERENCES

Ansari, N. A., & Sheikh, M. J. (2014). Evaluation of work Posture by RULA and REBA: A Case Study. *IOSR Journal of Mechanical and Civil Engineering*, *11*(4), 18-23.

Best Exercises for Lower Back Pain (2019, November 13). Retrieved from https://www.deskadvisor.org/desj-exercises-lower-back-pain/.

Department of Occupational Safety and Health Ministry of Human Resources. (2002). *Guidelines on Occupational Safety and Health for Seating at Work*.(I),1–29. https://doi.org/10.1007/s00702-010-0555-8.

Groves, R. M., Fowler Jr, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., & Tourangeau, R. (2011). *Survey methodology*(Vol. 561). John Wiley & Sons.

Hignett, S., & Mcatamney, L. (2000). Rapid Entire Body Assessment (REBA). *Applied Ergonomics*, *31*(2), 201–205. doi: 10.1016/s0003-6870(99)00039-3

International Ergonomics Association. (2015). Definition and domains of ergonomics. *Retrieved from http://www. iea. cc/whats/index. html*.

Jaffar, N., Abdul-Tharim, A. H., Mohd-Kamar, I. F., & Lop, N. S. (2011). A literature review of ergonomics risk factors in construction industry, *Procedia Engineering*, *20*, 89-97.

Kee, D. and W. Karwowski, (2007). A comparison of three observational techniques for assessing postural loads in industry. International Journal of Occupational Safety and Ergonomics, 13: 3-14. DOI: 10.1080/10803548.2007.11076704

OSHA 3125, (2000). Ergonomics, The study of Work.

Peterson, L.B. (2019, March 27). Ergonomics and Chair Adjustment Basics. Retrieved from https;//www.hon.com/blog/2015/04/16/ergonomics-and-chair-adjustment-basics.

Pheasant, S., & Haslegrave, C. M.(2006). *Body Space: Anthopometry, Ergonomics and the Design of Work, Third Edition*.

Priest, J. W., & Sanchez, J. M. (2001). *Product development and design for manufacturing: a collaborative approach to producibility and reliability*. New York: Marcel Dekker.

Sandberg, M. (2007). *Design for manufacturing: methods and applications using knowledge engineering*. *Retrieved from* http://www.wbdg.org/spac-types/auditorium

Stanton, N., A. Hedge, K. Brookhuis, E. Salas and H. Hendrick, (2004). Handbook of Human Factors and Ergonomics Methods. 1st Edn., CRC Press, ISBN-10: 0203489926, pp: 768.