UNIVERSITI PUTRA MALAYSIA

SIMULATION-BASED EVALUATION OF UPPER LIMB POSTURES ACROSS RANGE OF MOTION THROUGH MUSCLE ACTIVITY AND ENERGY EXPENDITURE

AZIZUL RAHMAN BIN ABD AZIZ

FK 2019 124

SIMULATION-BASED EVALUATION OF UPPER LIMB POSTURES ACROSS RANGE OF MOTION THROUGH MUSCLE ACTIVITY AND ENERGY EXPENDITURE

By

AZIZUL RAHMAN BIN ABD AZIZ

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Doctor of Philosophy

SIMULATION-BASED EVALUATION OF UPPER LIMB POSTURES ACROSS RANGE OF MOTION THROUGH MUSCLE ACTIVITY AND ENERGY EXPENDITURE

By

AZIZUL RAHMAN BIN ABD AZIZ

June 2019

Chair : Assoc. Prof. Siti Azfanizam Binti Ahmad, PhD
Faculty : Engineering

Ergonomics assessments is an indexing approach to human work activities embrace postures, load and repetitions. There are studies on ergonomics assessments comparison which have criticized the agreement among the outputs of the assessment. This research rises from an investigation by Fountain L.J. in 2003 regarding testing on 3 different postures scored by Rapid Upper Limb Assessment (RULA) on muscles activity and claimed that it was insignificant difference between measured electromyography with RULA scores. The objective of this research is to evaluate muscles activity and energy expenditure across postures deflection differences with Malaysian male anthropometry subject concerned. This evaluation covers upper limb postures as stated by RULA section A. The research was initiated with a verification study on three different elbow flexion posture angles with different scores by RULA on the prime mover muscles activity and total energy expenditure. The result has identified that variables changes existence between different postures tested and has permit for advance detail simulation using Universiti Putra Malaysia AnyBody Modelling System (AMS) software with more angles precision within the postures range of motion. The simulation outputs concerned were the specific postures prime mover muscles activity, maximum muscles activity and potential energy. The prime mover muscles simulation result has shown the co-contraction rhythm between the agonist and antagonist muscles. Maximum muscles activity represents the maximum muscles stress and potential energy expenditure as the fatigue tendency of specific posture. Both outputs were analyzed about the statistical significance using the P-value with 0.05 cut-off. Only the potential energy expenditure variable gives a P-value lower than 0.05 for all postures tested. The relationship model between the potential energy and the angle deflected has been developed to differentiate specific postures angles fatigue tendency. Both variables output value also deviated into low, medium and high magnitudes within the range. These results have enlightened the

postures risk index by kinesiology magnitude reference with scores by RULA. Besides that, maximum muscles activity is more applicable for postures stress measurement compared to prime mover muscles activity which only measures the stress on specific muscles.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN BERASASKAN SIMULASI BAGI POSTUR BAHAGIAN ATAS BADAN MERENTASI JULAT PERGERAKAN MELALUI AKTIVITI OTOT DAN PENGGUNAAN TENAGA

Oleh

AZIZUL RAHMAN BIN ABD AZIZ

Jun 2019

Pengerusi : Prof. Madya Siti Azfanizam Binti Ahmad, PhD
Fakulti : Kejuruteraan

Penilaian ergonomik adalah pendekatan indeks terhadap aktiviti kerja manusia merangkumi postur, beban dan pengulangan. Terdapat kajian perbandingan yang telah mengkritik persetujuan di antara output penilaian. Penyelidikan ini timbul daripada penyiasatan Fountain L.J. pada tahun 2003 terhadap tiga postur Penilaian Pantas Bahagian Atas Badan (RULA) yang berbeza pada aktiviti otot dan mendakwa bahawa perbezaan tidak ketara di antara elektromilogi yang diukur dengan skor RULA. Objektif kajian ini adalah bagi menilai aktiviti otot dan perbelanjaan tenaga merentasi perbezaan pesongan postur berkenaan subjek antropometri lelaki Malaysia. Penilaian ini merangkumi postur bahagian atas seperti yang dinyatakan RULA seksyen A. Penyelidikan ini dimulakan dengan kajian pengesahan mengenai tiga postur lenturan siku dengan skor RULA yang berbeza pada aktiviti otot penggerak utama dan jumlah perbelanjaan tenaga. Hasilnya telah mengenal pasti bahawa perubahan pembolehubah wujud antara postur yang diuji dan membenarkan bagi simulasi terpeinci menggunakan perisian AnyBody Modeling System (AMS) Universiti Putra Malaysia dengan lebih ketepatan sudut dalam julat gerakan postur. Hasil simulasi yang bersangkutan adalah aktiviti otot penggerak utama, aktiviti otot maksimum dan tenaga keupayaan postur. Hasil simulasi otot penggerak utama telah menunjukkan irama ko-kontraksi antara otot agonis dan antagonis. Aktiviti otot maksimum mewakili tekanan maksimum otot dan perbelanjaan tenaga keupayaan sebagai kecenderungan keletihan postur tertentu. Kedua-dua output dianalisis kepentingan statistik menggunakan nilai-P dengan potongan 0.05. Hanya pembolehubah tenaga keupayaan memberikan nilai-P lebih rendah daripada 0.05 bagi semua postur yang diuji. Model hubungan antara tenaga keupayaan dan sudut telah dibangunkan bagi membezakan sudut postur dengan kecenderungan keletihan. Kedua-dua nilai pembolehubah juga diasingkan kepada magnitud rendah, sederhana dan tinggi dalam julat pesongan. Hasil ini telah mencerahkan indeks risiko postur dengan rujukan

magnitud kinesiologi bersama skor RULA. Selain itu, aktiviti otot maksimum adalah lebih sesuai bagi pengukuran tekanan postur berbanding dengan aktiviti otot penggerak utama yang hanya mengukur tekanan pada otot tertentu.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and the Most Merciful, Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis. I would like to express my sincere appreciation to the chairman of the supervisory committee, Assoc. Prof. Dr. Siti Azfanizam Binti Ahmad for her innumerable support and supervision to complete this research study. Her kind assistance, encouragement, tolerance, understanding and commitment throughout this research study are very much valued. I would also like to express my gratitude to Associate Prof. Dr. Faieza Binti Abdul Aziz, Associate Prof. Dr. Siti Anom Binti Ahmad and Prof. Dr. Rosnah Binti Mohd Yusuff for their invaluable help of constructive comments and suggestions throughout the experimental and thesis works have contributed to the success of this research.

My deepest gratitude also dedicated to my family including my father, mother and all siblings including my dearest fiancée who have supported me morally and financially with continuous sacrifices in many ways. Besides that, not to be forgotten to my fellow comrades in Universiti Putra Malaysia for their knowledge sharing support in achieving our study objectives. Finally, double-thumbs-up to Universiti Putra Malaysia offices which have make ease of all the management matters.

I believe that without all these supports, my vision to produce this thesis will not be an easy endeavour.

I certify that a Thesis Examination Committee has met on 13 June 2019 to conduct the final examination of Azizul Rahman Bin Abd Aziz on his thesis entitled “Simulation-Based Evaluation of Upper Limb Postures Across Range of Motion Through Muscle Activity and Energy Expenditure” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student is awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Zulkiflie Bin Leman, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Khairol Anuar Bin Mohd Ariffin, PhD
Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Norzima Binti Zulkifli, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Zaidi Bin Mohd Ripin, PhD
Associate Professor
School of Mechanical Engineering
Universiti Sains Malaysia
Malaysia
(External Examiner)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 4 September 2019

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Siti Azfanizam Binti Ahmad, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Faieza Binti Abdul Aziz, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Siti Anom Binti Ahmad, PhD
Associate Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 September 2019

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ____________________ Date: ____________________

Name and Matric No.: Azizul Rahman Bin Abd Aziz (GS43628)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________
Name of Chairman of Supervisory Committee: Assoc. Prof. Dr. Siti Azfanizam Binti Ahmad

Signature: ______________________
Name of Member of Supervisory Committee: Assoc. Prof. Dr. Faieza Binti Abdul Aziz

Signature: ______________________
Name of Member of Supervisory Committee: Assoc. Prof. Ir. Dr. Siti Anom Binti Ahmad

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AEE	Activity Energy Expenditure
AMS	AnyBody Modelling System
BVH	Biovision Hierarchy
DC / AC	Direct Current / Alternate Current
ECG	Electrocardiogram
EMG	Electromyography
Epot	Potential Energy
FEA	Finite Element Analysis
GUI	Graphical User Interface
HAL	Hand Activity Level
KIM	Key Item Method
LUBA	Postural Loading on the Upper Body Assessments
MRCT	Massive Rotator Cuff Tear
NIOSH	National Institute of Occupational Safety and Health
OCRA	Occupational Repetitive Actions
OWAS	Ovako Working Posture Analysis System
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
SI	Strain Index
SOCSO	Social Security Organization (Malaysia)
TEE	Total Energy Expenditure
TLV	Threshold Limit Value
ULRA	Upper Limb Risk Assessment
WMSDs	Work Musculoskeletal Disorder(s)
WISHA	Washington Industrial Safety and Health Act
ACGIH	American Conference of Governmental Industrial Hygienists

CHAPTER 1

INTRODUCTION

This chapter expresses the basis of the research idea of evaluating the upper limb postures using kinesiology parameters. It discussed the reason behind this research conceptual framework development. The absence of quantitative measurements in practiced ergonomics assessment has been identified in review studies on the assessments. Related variables from previous studies have been identified for research orientations. At the end of this chapter, it clarified regarding the research problem statements, research objectives and research methodologies concerned in this evaluation study.

1.1 Research Background

The contextual of this study is about the ergonomics postures assessment output results or index disagreement. The postures assessment is the evaluation of the awkwardness level (Ergoweb, 2015). Awkward postures refer to the positions of the body while performing work activities that deviate significantly from the neutral position. The occurrence of awkward position makes the muscles operate less efficient which require more force expended to complete the works task. Work activities which frequently operated or repetitive with awkward postures existence will cause some disorders that may be painful during work or at rest. Work-related musculoskeletal disorders (WMSDs) is a group of painful disorders of muscles, tendons, and nerves such as carpal tunnel syndrome, tendonitis, thoracic outlet syndrome, and tension neck syndrome. WMSDs are also known by other related names such as repetitive motion injuries, repetitive strain injuries, cumulative trauma disorders, occupational cervicobrachial disorders, overuse syndrome, regional musculoskeletal disorders and soft tissue disorders which are associated with work patterns including fixed or constrained body positions, continual repetition of movements, force concentrated on small parts of the body and a pace of work that does not allow sufficient recovery between movements.

In 2004, a research stated that WMSDs involved with a median of 8 days absent from work compared with 6 days for all nonfatal injury and illness cases with the manufacturing and services industry sectors together accounted (Centers for Disease Control and Prevention, 2004). Furthermore, Commission on Behavioral and Social Sciences and Education (2011) reported WMSDs alleged for nearly 70 million physician office visits in the United States annually and estimation of 130 million total health care encounters including outpatient, hospital, and emergency room visits. In Malaysia from Social Security Organization (SOCSO) statistics in 2013, ergonomics-related cases stood at 694 from the total 2,360 occupational disease cases with every 4 occupational cases are reported to SOCSO, while one will be related to ergonomics. However, prevention of WMSDs can be practiced with ergonomic or human factor engineering tool or assessments by identifying the workplace or activities risks.

Various ergonomics analysis tools are available nowadays to assess the exposure to risks associated with WMSDs. These tools contemplation analysis can be the either qualitative, semi-quantitative or quantitative based measurement. Qualitative analysis tools gather basic observational data about a task related to discomforts. This kind of analysis tools generally requires the least amount of effort for the ergonomist. Job analysis checklists are an example of qualitative ergonomic tools with simple ergonomics analysis assesses whether a risk factor is existing. Semi-quantitative analysis tools include both judgment data and simple quantitative data.

Research has determined the ergonomics analysis tools likelihood used in the United State of America (USA) industries (Pascual & Naqvi, 2008). The ergonomic analysis tools used in USA result collected was Snook tables, the American Conference of Governmental Industrial Hygienists (ACGIH), Hand Activity Level (HAL), Threshold Limit Value (TLV), Washington Industrial Safety and Health Act (WISHA), Hand-Arm Vibration Analysis, National Institute of Occupational Safety and Health (NIOSH) lifting equation, the Moore-Garg Strain Index (SI) and biomechanical analyses. This research has used survey method to count the likelihood of ergonomics analysis tools and methods used by the certified professional ergonomists in America yet investigating which tools were mostly practiced in the industries and the easiness of those tools to be used by the ergonomist as a WMSDs assessment tool. Figure 1.1 shows the result of ergonomic tools has been used in USA industries adapted from the research survey.

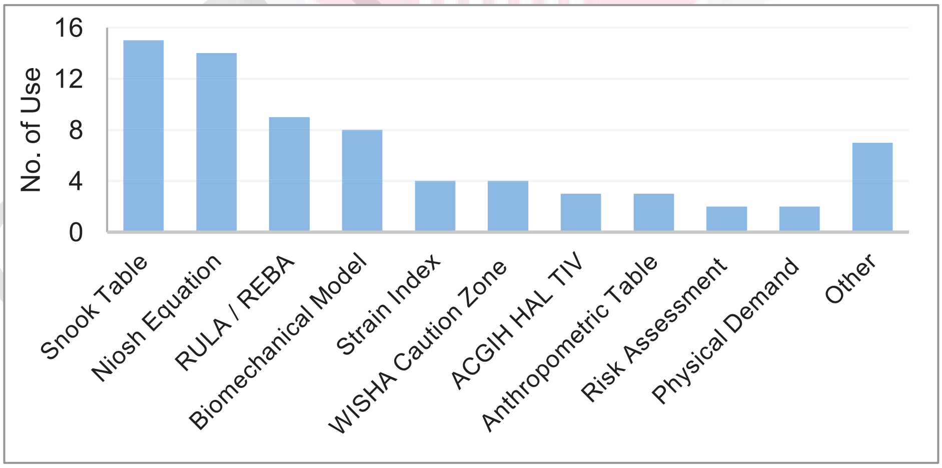


Figure 1.1: Ergonomics Tools Level of Use in USA's Manufacturing Industry (Pascual & Naqvi, 2008)

1.2 Problem Statement

From the literature review conducted across ergonomics assessments, interest has been raised to investigate concerned parameters in indexing WMSDs used by the ergonomic assessments. Comparative studies among ergonomic assessments have identified some gaps which require additional details about indexing the effort or risk on the human body. Likewise, there was also a lack of initiative in embedding other disciplines of human study to achieve the ergonomics assessments objectives of WMSDs prevention. A study by Roman-Liu (2014) had begun a comparative analysis of techniques in measuring WMSDs. Ten ergonomics assessments had been considered as the samples or subjects to be grouped according to the assessment's focus which also compared to their specific features and results. The ergonomics assessments compared were key item method (KIM), NIOSH Lifting Equations, ovako working posture analysis system (OWAS), postural loading on the upper body assessments (LUBA), occupational repetitive actions (OCRA), strain index (SI), upper limb risk assessments (ULRA), rapid upper limb assessments (RULA) and rapid entire body assessment (REBA). This study concluded that the concepts of measuring risk in dissimilar approaches can be used to develop solutions leading to a comprehensive method suit for all work tasks and all parts of the body. It also has suggested for additional studies were obligatory to verify the accepted output result and to set some parameters standardization that would make consolidation possible.

Another research by Rowshani et al. (2013) has compared RULA with SI and Nordic questionnaire intentionally to investigate the agreements between both assessments on high-risk level task. This cross-section study has been conducted on 50 workers form the assembly line to be evaluated by those ergonomics assessments. Rendering to RULA method, 52% of the cases for the right hand and 54% for the left hand were at grade 3 and 2% for both hands were at grade 4. In the automatic PC board tester job 25% of the cases in both hands were at grade 4. According to the SI scoring, 64% of the cases in the right hand and 42% of them in the left hand were unsafe. More than that, the most common sicknesses were seen in waist and shoulder (48%), neck (28%) and back (24%). There was a correlation between work experience and shoulder pain (P=0.016) and leg pain (P=0.032) and between the results of the SI method in the left hand and shoulder pain (P=0.002). Kappa coefficient showed the agreement between the results of both RULA and SI methods.

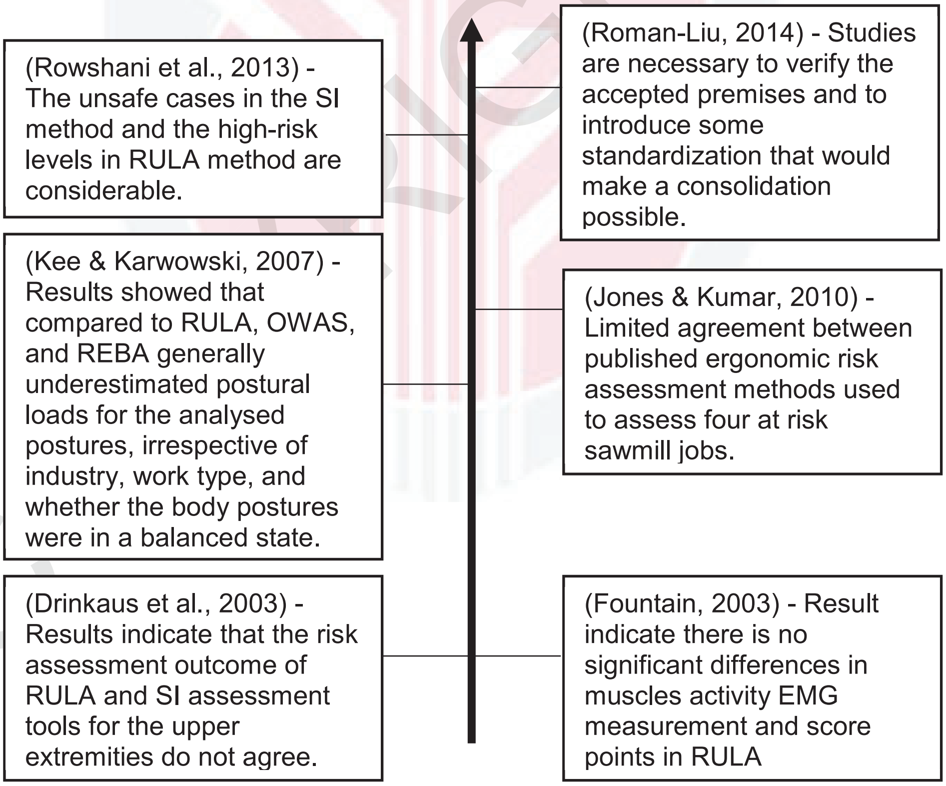
Nevertheless, concluded in another study by Jones & Kumar (2010) about demonstrated limited agreement between RULA, REBA, SI, OCRA and American Conference of Governmental Industrial Hygienist's threshold limit value for mono-task handwork (ACGIH TLV) methods used to assess four at-risk sawmill jobs. This study used workers 18 to 65 years of age performing four sawmill occupations observed to be associated with upper extremity WMSDs. It was recruited from four sawmill facilities in Alberta, Canada. 93 workers volunteered to take part in the study out of the population of 93 (100% participation rate). Relatively large differences version in the ability to identify jobs as at risk was identified between methods. This difference in agreement present when the jobs were thought about individually points shows the appropriateness of the methods may be affected by the exposure profile of the job.

A study by Kee & Karwowski (2007) compared 3 observational techniques for assessing the postural load, namely, OWAS, RULA, and REBA. The comparison was based on the evaluation results generated by the classification techniques using 301 working postures. All postures were sampled from the iron and steel, electronics, automotive, and chemical industries, and a general hospital. While only about 21% of the 301 postures were classified at category level 3 or 4 by both OWAS and REBA, about 56% of the postures were classified into action level 3 or 4 by RULA. The method reliability for postural load category between OWAS and RULA was just 29.2%, and the reliability between RULA and REBA was 48.2%. These results showed that compared assessments of RULA, OWAS, and REBA generally underestimated postural loads for the analyzed postures, irrespective of industry, work type, and if the body postures were in a balanced state.

Reinforced by another comparison study by Drinkaus et al. (2003) which compared RULA with SI assessments about the output result agreement. The ergonomic risk of upper extremities on 244 automotive assembly plant tasks was evaluated using RULA and SI. The results of each tool were compared for each task. This study provides practical insight into the methods used in each tool which compared only the ergonomic risk outputs from each tool and yet the study did not track the question of which tool best predicts injury. The kappa score was 0.11, indicating little agreement between the outputs of those tools. This is supported by the lack of monotonicity with a gamma score of 0.1. These results revealed assessment tools for the upper extremities do not agree between RULA and SI with only 75% agreement for high risk and 61% for low risk.

A study by Fountain L. J. (2003) has correlated a musculoskeletal stress quantitative variable that varies the working conditions awkwardness referred to as human physiology with an ergonomic assessment. This study has examined RULA by muscle activity measured using electromyography (EMG). This study has been conducted with RULA which is based on surveys of postures discomfort sampling tool used to specifically score the individual worker's postures discomfort level. The experiment was conducted on 20 participants where each subject performed a 30-min typing task on a computer in 3 working postures based on different RULA scores. The surface EMG measurement was done onto 4 muscles which are upper trapezius, anterior deltoid, biceps brachii and forearm extensor. The result of this study has concluded that there was no significant difference between the arrangement of the RULA score with EMG muscle activity testing where the P-value for each muscle readings was larger than 0.05. This research has led in evaluating kinesiology variables measurement with discomfort scores by RULA.

RULA was developed to evaluate the exposure of individual workers to ergonomic risk factors associated with upper extremity WMSDs. RULA ergonomic assessment tool has considered biomechanical and postural load requirements of job tasks or demands on the neck, trunk and upper extremities. Revised with ergonomics tool study published by Budnick (2012) has specified RULA occupied with a strong focus on posture, but a weak focus on force, repetition and duration. The researcher found the duty cycle to be so important in predicting upper extremity risk that could derive an equation using only the duty cycle to predict acceptable levels of force exertion for repetitive tasks. Therefore, it is significant that RULA does not adequately consider duration so in single-handedly it is weak recognition of force and repetition. It is best applied to jobs characterized by static postures with lower anxiety for force and repetition factors. It is easy to overestimate the risk of a job with RULA if the analyst focuses only on extreme postures especially if those extremes have short durations. In other cases, regarding jobs involving forces, repetition, and durations RULA may underestimate the risk occupy on the workers. Figure 1.2 shows the illustration of the previous research summary about the ergonomics assessment conclusion and recommendation proposing for detailed justification research.



(Rowshani et al., 2013) - The unsafe cases in the SI method and the high-risk levels in RULA method are considerable.

(Kee & Karwowski, 2007) - Results showed that compared to RULA, OWAS, and REBA generally underestimated postural loads for the analysed postures, irrespective of industry, work type, and whether the body postures were in a balanced state.

(Drinkaus et al., 2003) - Results indicate that the risk assessment outcome of RULA and SI assessment tools for the upper extremities do not agree.

(Roman-Liu, 2014) - Studies are necessary to verify the accepted premises and to introduce some standardization that would make a consolidation possible.

(Jones & Kumar, 2010) - Limited agreement between published ergonomic risk assessment methods used to assess four at risk sawmill jobs.

(Fountain, 2003) - Result indicate there is no significant differences in muscles activity EMG measurement and score points in RULA

Figure 1.2: Related Research's Result Timeline

1.3 Research Questions

Referring to the previous problem statement, inquiries or questions have been raised which can be crossed with further detail parameters analysis. These questions acting as the fundamental core of the research. Following are the research questions imposed on postures condition variety assessment.

i. What are the postures prime mover muscles according to the kinesiology field?
ii. How do specific postures differentiate by the quantitative measurement of prime mover muscles activity and kinematics positioning potential energy along with the postures range of motion?
iii. Regarding the disagreement between ergonomic assessments, how do both kinesiology variables (muscles activity and energy expenditure) values statistically indexed?

1.4 Research Objectives

From the research questions above, the aim has been arranged for the evaluation of upper limb postures within the deflection range using simulation, followed by verification and validation. These research objectives were.

i. To analyze specific upper limb postures including shoulder flexion, abduction, external rotation, elbow flexion, wrist flexion, abduction and pronation prime mover muscles activity.
ii. To develop statistical based risk index by muscle activity and kinematic potential energy expenditure regarding specific upper limb postures range of motion (ROM).
iii. To develop the model of kinematic potential energy expenditure across upper limb posture deflection angles.

1.5 Research Scopes

This research has focused on Malaysian male subject since this group composed 61.1% of total Malaysian workers (Mahidin, 2018). Similarly, the evaluation was concentrated only on specific upper limb postures as mentioned in RULA section A. The testing was conducted on a specific single joint displacement in a standing condition to refine the effects of the combination of variations. The testing period was fixed at 30-minutes to replicate the study duration by Fountain L. J. (2003) with the static and free-load condition to distinguish only the postures positioning among the upper limb.

1.6 Significance of the Study

Beholding at limited agreement among ergonomic assessments, recommendations have projected for additional quantitative measurement to differentiate the upper limb postures risk index. This relationship evaluation of upper limb working postures and kinesiological parameters analysis believed to be an additional reference on how much precisely the muscles activity variable varies with the working postures deflections diversity. The specific postures muscles activity was considered as stress onto the muscles or the human body. Reinforced by another variable of energy expenditure which also represents the effort of the human body to upkeep the postures kinematic changes. Development of a quantitative based relationship model or equation can be compared to existing working postures assessments which will provide a comprehensive and clearer evaluation of ergonomics risk factor.

1.7 Thesis Layout

Chapter 1 has discussed regarding the research origin, intentions and the scopes considered to answer the questions developed from problem statements founded. The literature and studies cited in Chapter 2 challenge the different concept, understanding, ideas and different development related to study the enrolment from the past up to the present and which serves as the research method in developing the research methodology or design. Chapter 3 presents the methods to be used in this study. Here also describes the subjects of the study, the instruments used, the procedure of data gathering, and the statistical treatment of the data. Continue with Chapter 4 which discussed the collected data with the analysis and statistical treatment. The discussions were mapped to answer the research questions extracted initially. The thesis was then closed with Chapter 5 consist of the research objectives achievement with founded results discussed and the recommendation for future research interest. This chapter has summarized the points captured along the research methodology.

REFERENCES

Al-Mulla, M. R., Sepulveda, F., & Colley, M. (2011). A Review of Non-Invasive Techniques to Detect and Predict Localised Muscle Fatigue. *Sensors*, *11*(4), 3545–3594. https://doi.org/10.3390/s110403545

Alter, M. J. (2004). *Science of Flexibility (Third edition)* (3rd ed.). Human Kinetics. Retrieved from https://books.google.com.my/books?id=scienceofflexibilityco

American Academy of Orthopaedic Surgeons. (2011). Average Ranges of Motion. https://doi.org/10.1017/CBO9781107415324.004

Anderson, E., Wybo, C., & Bartol, S. (2010). An Analysis of Agreement between MMG vs. EMG Systems for Identification of Nerve Location During Spinal Procedures. *The Spine Journal*, *10*(9), S93–S94. Retrieved from http://www.thespinejournalonline.com/article/S1529-/abstract

Anthony N.T., & Keir P.J., (2010). Effects of Posture, Movement and Hand Load on Shoulder Muscle Activity. *Journal of Electromyography and Kinesiology*. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/19473855

AnyBody Technology Inc. (2015). Why Musculoskeletal Modeling ? The AnyBody Modeling System.

Atlanta, A. F. (2016). Elbow Anatomy: An Inside Look at the Structure of The Elbow. Retrieved October 7, 2015, from http://www.arthritis.org/about-arthritis/where-it-hurts/elbow-pain/elbow-anatomy.php

Barauce Bento, P. C. (2015). Postural Control. *Medicine & Science in Sports & Exercise*, *47*, 314. https://doi.org/10.1249/01.mss.0000477278.52624.45

Biodigital Human. (2013). BioDigital Human. *Choice Reviews Online*, *50*(10), 50-5617-50–5617. https://doi.org/10.5860/choice.50-5617

Blanc, Y., & Dimanico, U. (2010). Electrode Placement in Surface Electromyography (sEMG) ”Minimal Crosstalk Area“ (MCA). *The Open Rehabilitation Journal*, *3*(1), 110–126. https://doi.org/10.2174/1874943701003010110

Blanchonette, P. (2010). Jack Human Modelling Tool: A Review. *Science And Technology*, 1–37. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a518132.pdf

Bronzino, E. J. D. (2000). *Chapter 14 - Principles of Electromyography*. *Biomedical Engineering*. Boca Raton: CRC Press LLC. Retrieved from http://www.bioingenieria.edu.ar/academica/catedras/bioingenieria2/archivos/apuntes/principles of electromyography.pdf

Budnick, P. (2012). *The Trouble with RULA (Rapid Upper Limb Assessment)*. *The Ergonomics Report*. Retrieved from https://ergoweb.com/the-trouble-with-rula-rapid-upper-limb-assessment-2/

Bullock, J., Boyle, J., & Wang, M. B. (2001). Muscle contraction. *NMS Physiology*.

CamNtech. (2010). The Actiheart Guide to Getting Started. *Options*, *37*(Apr), 1–39. Retrieved from http://www.camntech.com/files/The_Actiheart_Guide_to_Getting_Started.pdf

Centers for Disease Control and Prevention. (2004). *NIOSH Workers Health Chartbook* (146th ed.). Washington DC: NIOSH.

Chaffin, D. B. (1973). Localized Muscle Fatigue - Definition and Measurement. *Journal of Occupational and Environmental Medicine*, (April). Retrieved from https://www.researchgate.net/publication/232184472_Localized_Muscle_Fatigue_-_Definition_and_Measurement

Chowdhury, R., Reaz, M., Ali, M., Bakar, A., Chellappan, K., & Chang, T. (2013). Surface Electromyography Signal Processing and Classification Techniques. *Sensors*, *13*(9), 12431–12466. https://doi.org/10.3390/s130912431

Collet, Y., Ttreault, P., Rasmussen, J., Nuo, N., & Hagemeister, N. (2007). Computational Modeling of A Prosthetic Shoulder: Our Experience with The Anybody Modeling System. In *Proceedings of the 18th IASTED International Conference* (p. 624).

Collie, B., & Mix, C. (2011). Kinesiology: The Study of Human Motion. Retrieved April 5, 2016, from http://www.hawaiianshirtray.com/anatomy-physiology/kinesiology-study-human-motion/

Commission on Behavioral and Social Sciences and Education. (2011). *Musculoskeletal Disorders And The Workplace: Low Back And Upper Extremities. Panel on Musculoskeletal Disorders and the Workplace*. Washington, DC. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK222446/

Cooper, G., & Hausman, R. (2007). *The Cell: A Molecular Approach* (2nd ed.). https://doi.org/10.1017/CBO9781107415324.004

Corbett, E. a., Perreault, E. J., & Kuiken, T. a. (2011). Comparison Of Electromyography and Force as Interfaces for Prosthetic Control. *The Journal of Rehabilitation Research and Development*, *48*(6), 629. https://doi.org/10.1682/JRRD.2010.03.0028

Corlett, E. N. (2006). Background to Sitting at Work: Research-Based Requirements for the Design of Work Seats. *Ergonomics*, *49*(14), 1538–1546. https://doi.org/10.1080/00140130600766261

Crossing, M. (2006). Muscles Crossing the Shoulder joint: Movements of the Arm. Retrieved October 29, 2015, from http://www.kean.edu/~jfasick/docs/Fall Semester Lectures Chapt. 1-15 ’07/Chapter 10C.pdf

Cummings, B. (2006). The Muscular System (pp. 302–307). Pearson Education, Inc. Retrieved from http://www.kean.edu/~jfasick/docs/Fall Semester Lectures Chapt. 1-15 ’07/Chapter 10A.pdf?ref=binfind.com/web

Dahiru, T. (2008). P-Value, A True Test of Statistical Significance? A Cautionary Note. *Annals of Ibadan Postgraduate Medicine*, *6*(1), 21–26. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4111019/

Damsgaard, M., Rasmussen, J., Christensen, S. T., Surma, E., & de Zee, M. (2006). Analysis of Musculoskeletal Systems in the Anybody Modeling System. *Simulation Modelling Practice and Theory*, *14*(8), 1100–1111. https://doi.org/10.1016/j.simpat.2006.09.001

David Terfera, S. J. (2012). *Clinical Anatomy for Dummies*. Retrieved from http://www.dummies.com/how-to/content/the-joints-of-the-shoulder-girdle.html

De Jong, P., de Zee, M., Hilbers, P. A. J., Savelberg, H. H. C. M., van de Vosse, F. N., Wagemakers, A., & Meijer, K. (2006). Multi-Body Modelling of Recumbent Cycling: An Optimisation of Configuration and Cadence. In *Poster presented at the 11th Symposium of the Flemish Society of Kinesiology, Antwerp, Belgium* (pp. 1-1 p.). Retrieved from https://github.com/AnyBody/support/blob/master/Wiki_Files/Validation_Examples/Dejong.pdf

De Luca, C J. (1997). The Use of Surface Electromyography in Biomechanics. *Journal of Applied Biomechanics*, *13*, 135–163. https://doi.org/citeulike-article-id:2515246

Dee Unglaub Silverthorn. (2009). *Human Physiology: An Integrated Approach*. Pearsin Benjamin Cummings. Retrieved from https://docs.google.com/document/d/19L5fGXLmbKbqcbx1-

Delany, J. P. (2012). Measurement of Energy Expenditure. *Pediatric Blood and Cancer*, *58*(1), 129–134. https://doi.org/10.1002/pbc.23369

Delsys. (2016). Amplitude Analysis : Normalization of EMG to Maximum Voluntary Contraction (MVC). Retrieved October 5, 2016, from http://www.delsys.com/emgworks-analysis-techniques-using-emgscript/

Department of Social and Health Service. (2003). *Range of Joint Motion Evaluation Chart*. Retrieved from https://www.dshs.wa.gov/sites/default/files/FSA/forms/pdf/13-585a.pdf

Drinkaus, P., Sesek, R., Bloswick, D., Bernard, T., Walton, B., & Joseph, B. (2003). Comparison of Ergonomic Risk Assessment Outputs from Rapid Upper Limb Assessment and the Strain Index for Tasks in Automotive Assembly Plants. *Work*, *21*(2), 165–172. Retrieved from https://medicine.utah.edu/rmcoeh/files/drinkaus_2003_pub.pdf

Dubowsky, S. R., Rasmussen, J., Sisto, S. A., & Langrana, N. A. (2008). Validation of a Musculoskeletal Model of Wheelchair Propulsion and its Application to Minimizing Shoulder Joint Forces. *Journal of Biomechanics*, *41*(14), 2981–2988. https://doi.org/10.1016/j.jbiomech.2008.07.032

Ebneshahidi, A. (2015). Anatomical Terminology. Retrieved August 30, 2016, from http://www.lamission.edu/lifesciences/AliAnat1/Chap1-anatomical terminology.pdf

Ekstrom, R. A., Soderberg, G. L., & Donatelli, R. A. (2005). Normalization Procedures using Maximum Voluntary Isometric Contractions for the Serratus Anterior and Trapezius Muscles during Surface EMG Analysis. *Journal of Electromyography and Kinesiology*, *15*(4), 418–428. https://doi.org/10.1016/j.jelekin.2004.09.006

Ergoweb. (2015). Ergonomic Concept. Retrieved February 16, 2016, from https://ergoweb.com/knowledge/ergonomics-101/concepts/

Figueiredo Filho, D. B., Paranhos, R., da Rocha, E. C., Batista, M., da Silva Jr., J. A., D. Santos, M. L. W., & Marino, J. G. (2013). When is Statistical Significance Not Significant? *Brazilian Political Science Review*, *7*(1), 31–55. https://doi.org/10.1590/S1981-38212013000100002

Floyd, R. T. (University of W. A. (2004). *Manual of Structural Kinesiology*. *British journal of sports medicine*. McGraw-Hill. https://doi.org/10.1136/bjsm.19.3.151-a

Fountain, L. J. (2003). Examining RULA's Postural Scoring System With Selected Physiological And Psychophysiological Measures. *International Journal of Occupational Safety and Ergonomics : JOSE*, *9*(4), 383–392. https://doi.org/10.1080/10803548.2003.11076576

Frey-Law, L. A., & Avin, K. G. (2013). Muscle Coactivation: A Generalized or Localized Motor Control Strategy? *Muscle and Nerve*, *48*(4), 578–585. https://doi.org/10.1002/mus.23801

Hagberg, M. (1981). Electromyographic Signs of Shoulder Muscular Fatigue in Two Elevated Arm Positions. *American Journal of Physical Medicine*, *60*(3), 111–121. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/7246723

Hao, D., Cao, L., Wang, Y., Zhang, S., Rong, Y., Zheng, D., & Yang, L. (2017). Effects of Force Load, Muscle Fatigue, and Magnetic Stimulation on Surface Electromyography during Side Arm Lateral Raise Task: A Preliminary Study with Healthy Subjects. *BioMed Research International*, *2017*, 1–9. https://doi.org/10.1155/2017/8943850

Herberts, P., Kadefors, R., & Broman, H. (1980). Arm Positioning in Manual Tasks and Electromyographic Study of Localized Muscle Fatigue. *Ergonomics*, *23*(7), 655–665. https://doi.org/10.1080/00140138008924780

Horak, F. B. (2006). Postural Orientation and Equilibrium: What Do We Need to Know About Neural Control of Balance to Prevent Falls? *Age and Ageing*, *35*(SUPPL.2), 7–11. https://doi.org/10.1093/ageing/afl077

Irfan, M. R. M., Sudharsan, N., Santhanakrishnan, S., & Geethanjali, B. (2011). A Comparative Study of EMG and MMG Signals for Practical Applications. *2011 International Conference on Signal, Image Processing and Applications*, *21*, 106–110. Retrieved from http://www.ipcsit.com/vol21/22-ICSIA2011-A1088.pdf

Islam, M. A., Sundaraj, K., Ahmad, R. B., & Ahamed, N. U. (2013). Mechanomyogram for Muscle Function Assessment: A Review. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0058902

Itoh, Y., Akataki, K., Mita, K., Watakabe, M., & Itoh, K. (2004). Time-Frequency Analysis of Mechanomyogram during Sustained Contractions with Muscle Fatigue. *Systems and Computers in Japan*, *35*(1), 26–36. https://doi.org/10.1002/scj.10528

Jarmey, C. (2008). *The Concise Book of Muscles* (2nd ed.). North Atlantic Books.
John Michael. (2000). Prosthetic Principles Upper Extremity Amputations. Los Angeles: University of California. Retrieved from http://www.oandplibrary.org/reference/uclamanual/UCLA-02.pdf

John Robert Taylor. (2005). Force as the Gradient of Potential Energy. In *Classical Mechanics* (pp. 116–117). Science. Retrieved from https://books.google.com.my/books?id=P1kCtNr-

Jones, T., & Kumar, S. (2010). Comparison of Ergonomic Risk Assessment Output in Four Sawmill Jobs. *International Journal of Occupational Safety and Ergonomics : JOSE*, *16*(1), 105–111. https://doi.org/10.1080/10803548.2010.11076834

Karmegam, K., Sapuan, S. M., Ismail, M. Y., Ismail, N., Bahri, M. T. S., & Shuib, S. (2011). Anthropometric Study Among Adults of Different Ethnicity in Malaysia. *International Journal of the Physical Sciences*, *6*(4), 777–788. https://doi.org/10.5897/IJPS10.310

Kee, D., & Karwowski, W. (2007). A comparison of three observational techniques for assessing postural loads in industry. *International Journal of Occupational Safety and Ergonomics : JOSE*, *13*(1), 3–14.

https://doi.org/10.1080/10803548.2007.11076704

Kenneth, S. S., & Carol, M. P. (2012). *Anatomy and physiology: The unity of form and function*. New York: McGraw-Hill. Boston, Massachusetts, USA.

Kevin T. Patton. (2015). Anatomy And Physiology. In *Elsevier Health Sciences* (9th ed., pp. 797–780). Elsevier Health Sciences. Retrieved from https://books.google.com.my/books?id=prime mover muscles of shoulder

Knudson, D. (2007). *Fundamentals of Biomechanics*. (2, Ed.). Springer. https://doi.org/10.15713/ins.mmj.3

Koopman, B., Grootenboer, H. J., & de Jongh, H. J. (1995). An Inverse Dynamics Model for the Analysis, Reconstruction, and Prediction of Bipedal Walking. *J. Biomech.*, *28*(11), 1369–1376. Retrieved from https://www.sciencedirect.com/science/article/pii/0021929094001857

Krans, J. L. (2010). The Sliding Filament Theory of Muscle Contraction. *Nature Education*, *3*(9), 66. Retrieved from http://www.teachpe.com/anatomy/sliding_filament.php

Kristindockter. (2011). Muscle Physiology - Muscle Structure. Retrieved August 25, 2016, from https://kristindockter.wikispaces.com/Muscle+Physiology

Kulkarni, V., Al-Rfou, R., Perozzi, B., & Skiena, S. (2015). Statistically Significant Detection of Linguistic Change. *Proceedings of the 24th International Conference on World Wide Web (WWW '15)*, 625–635. https://doi.org/10.1145/2736277.2741627

Kumar, S. (2008). Introduction and Terminology. In *Shrawan Kumar. Muscle strength* (1st ed., p. 113). Boca Raton: CRC Press.

Lewis, G. N., MacKinnon, C. D., Trumbower, R., & Perreault, E. J. (2010). Co-Contraction Modifies the Stretch Reflex Elicited in Muscles Shortened by A Joint Perturbation. *Experimental Brain Research*, *207*(1–2), 39–48. https://doi.org/10.1007/s00221-010-2426-9

Lippert, L. (2011). *Clinical Kinesiology and Anatomy of the Upper Extremities*. *Clinical Kinesiology and Anatomy* (5th ed.). Philadelphia: F. A. Davis Company. Retrieved from https://books.google.com.my/books?id=dXH2AAAAQBAJ

Luca, Carlo J De. (2002). *Surface Electromyography : Detection and Recording*. *DelSys Incorporated* (Vol. 10). Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:surface+electromyography+:+detection+and+recording#0

Mahesh, J. (2009). *Textbook Of Engineering Physics* (1st ed.). PHI Learning Pvt. Ltd. Retrieved from https://books.google.com.my/books?id=Fundamental forces and laws: a brief review

Mahidin, M. U. (2018). *Principal Statistics of Labour Force, Malaysia, Second Quarter (Q2) 2018*. Retrieved from https://dosm.gov.my/v1/index.php?

Mansfield, P. J., & Neumann, D. A. (2008). *Essentials of Kinesiology for the Physical Therapist Assistant - Text and E-Book Package*. Elsevier Science Health Science Division. Retrieved from https://books.google.com.my/books?id=qdK3OgAACAAJ

McAtamney, L., & Nigel Corlett, E. (1993). RULA: A Survey Method For The Investigation of Work-related Upper Limb Disorders. *Applied Ergonomics*, *24*(2), 91–99. https://doi.org/10.1016/0003-6870(93)90080-S

McCall, R. P. (2010). Energy, Work and Metabolism. In *Physics of the Human Body* (p. 69). JHU Press. Retrieved from https://books.google.com.my/books?id=Energy, Work and Metabolism

Michael J. Alter. (2004). *Science of Flexibility*. *Human Kinetics* (Vol. 32). Health & Fitness. Retrieved from http://books.google.com.my/books?id=-AfNV215sPAC&lpg=PA1&pg=PA20#v=onepage&q&f=false

Microsoft. (2017). Chart Trendline Formula is Inaccurate in Excel. Retrieved from https://support.microsoft.com/en-my/help/211967/chart-trendline-formula-is-inaccurate-in-excel

Mitagaki. (2015). Planes of The body. Retrieved August 30, 2016, from http://www.embodi3d.com/gallery/image/314-planes-of-the-body/

Mukhopadhyay, S., Das, S. K., & Chakraborty, T. (2012). Computer Aided Design in Digital Human Modeling for Human Computer Interaction in Ergonomic Assessment : A Review. *International Journal of Advanced Computer Research*, *2*(4), 133–138. Retrieved from http://www.academia.edu/9076125/Computer_Aided_Design_in_Digital_Human_Modeling_for_Human_Computer_Interaction_in_Ergonomic_Assessment_A_Review_Assistant_Professor_1_and_Doctoral_Fellows

Nishihara, K., & Isho, T. (2012). Location of Electrodes in Surface EMG. *EMG Methods for Evaluating Muscle and Nerve Function*, 17–30. https://doi.org/10.5772/25421

Oatis, C. A. (2003). The Mechanics and Pathomechanics of Human Movement.

Pascual, S. a., & Naqvi, S. (2008). An Investigation of Ergonomics Analysis Tools Used in Industry in the Identification of Work-related Musculoskeletal Disorders. *International Journal of Occupational Safety and Ergonomics*, *14*(2), 237–245.

Petrofsky, J., Batt, J., Hye, J. S., Jones, R., Ushak, N., Tucker, J. P., … Billings, T. (2006). Muscle use during Isometric Cocontraction of Agonist-Antagonist Muscle Pairs in the Upper and Lower Body Compared to Abdominal Crunches and a Commercial Multi Gym Exerciser. *Journal of Applied Research*, *6*(4), 300–328. Retrieved from http://jrnlappliedresearch.com/articles/Vol6Iss4/Petrofsky.pdf

Pierce, P. A. (2013). *Fatigue: Neural and Muscular Mechanisms*. *Springer Science & Business Media*. https://doi.org/10.1017/CBO9781107415324.004

Pinheiro Volp, a C., Esteves de Oliveira, F. C., Duarte Moreira Alves, R., Esteves, E. a, & Bressan, J. (2011). Energy Expenditure: Components and Evaluation Methods. *Nutricion Hospitalaria : Organo Oficial de La Sociedad Espanola de Nutricion Parenteral y Enteral*, *26*(3), 430–440. https://doi.org/10.3305/nh.2011.26.3.5181

Place, N., Bruton, J. D., & Westerblad, H. (2009). Mechanisms of Fatigue Induced by Isometric Contractions in Exercising Humans and in Mouse Isolated Single Muscle Fibres. *Clinical and Experimental Pharmacology and Physiology*, *36*(3), 334–339. https://doi.org/10.1111/j.1440-1681.2008.05021.x

Poirson, E., Delangle, M., Poirson, E., Delangle, M., Poirson, E., & Delangle, M. (2015). Comparative Analysis of Human Modeling Tools. *International Digital Human Modeling Symposium*, 1–7. Retrieved from https://hal.archives-ouvertes.fr/hal-01240890/document

Priest, J. (2004). Mechanical Energy, *4*(abbreviated m), 1–12. Retrieved from https://www.physicsclassroom.com/class/energy/Lesson-1/Mechanical-Energy

Qualter, J., Sculli, F., Oliker, A., Napier, Z., Lee, S., Garcia, J., … Triola, M. (2012). The BioDigital human: A web-based 3D Platform for Medical Visualization and Education. *Studies in Health Technology and Informatics*, *173*, 359–361. https://doi.org/10.3233/978-1-61499-022-2-359

Robertson, D. G. E. (2015). Electromyography: Processing. *Biomechanics Laboratory, School of Human Kinetics Ottawa, University Of*. Retrieved from www.health.uottawa.ca/biomech/courses/apa4311/emg-p2.pps

Roger William University. (2017). Calculating and Displaying Regression Statistics in Excel. Retrieved from http://rwu.edu/sites/default/files/downloads/fcas/mns/calculating_and_displaying_regression_statistics_in_excel.pdf

Roman-Liu, D. (2014). Comparison of Concepts in Easy-to-Use Methods for MSD Risk Assessment. *Applied Ergonomics*, *45*(3), 420–427. https://doi.org/10.1016/j.apergo.2013.05.010

Ron Kurtus. (2016). List of Worldwide AC Voltages and Frequencies . Retrieved November 24, 2016, from http://www.school-for-champions.com/ac_world_volt_freq_list.htm#.WDatnvl97IU

Rosenhahn, B., Klette, R., & Metaxas, D. (2006). Human Motion - Understanding, Modeling, Capture and Animation. *Human Motion - Understanding, Modelling, Capture, and Animation*, 1–18. Retrieved from http://drops.dagstuhl.de/opus/volltexte/2006/721/06241_collection.721.pdf

Rowshani, Z., Mortazavi, S. B., Khavanin, A., Mirzaei, R., & Mohseni, M. (2013). Comparing RULA and Strain Index Methods for the Assessment of the Potential Causes of Musculoskeletal Disorders in the Upper Extremity in an Electronic Company in Tehran. *Kashan University of Medical Sciences*, *17*(1), 61–70. Retrieved from http://feyz-journals.kaums.ac.ir/index.php/feyz-

Sawyer, S. (2010). Human Energy. In *Dialectical Anthropology* (Vol. 34, pp. 67–75). https://doi.org/10.1007/s10624-009-9122-9

Schüldt, K., Ekholm, J., Harms-Ringdahl, K., Arborelius, U. P., & Németh, G. (1987). Influence of Sitting Postures on Neck and Shoulder E.M.G. during Arm-hand Work Movements. *Clinical Biomechanics*, *2*(3), 126–139. https://doi.org/10.1016/0268-0033(87)90003-9

Scott, D. (2002). Important Factors in Surface EMG Measurement. *Measurement*, 1–17. Retrieved from http://edge.rit.edu/content/P08027/public/IRB/Papers/intro_EMG.pdf

Shin, Y.-H., Choi, J.-S., Kang, D.-W., Seo, J.-W., Lee, J.-H., Kim, J.-Y., … Tack, G.-R. (2015). A Study on Human Musculoskeletal Model for Cycle Fitting: Comparison with EMG. *World Academy of Science, Engineering and Technology, International Journal of Biomedical and Biological Engineering*, *2*(2), 92–96. Retrieved from https://www.waset.org/abstracts/20629

Sircar, S. (2008). Muscle Elasticity. In *Principles of Medical Physiology* (4th ed., p. 113). New York: Thieme.

Squire, J. M. (2016). Muscle contraction: Sliding Filament History, Sarcomere Dynamics and the Two Huxleys. *Global Cardiology Science and Practice*, *2016*(2). https://doi.org/10.21542/gcsp.2016.11

Tarata, M. T. (2003). Mechanomyography Versus Electromyography, in Monitoring the Muscular Fatigue. *Biomedical Engineering Online*, *2*, 3. https://doi.org/10.1186/1475-925X-2-3

TechMeAnatomy. (2015a). The Radioulnar Joints. Retrieved May 7, 2016, from http://teachmeanatomy.info/upper-limb/joints/radioulnar-joints/

TechMeAnatomy. (2015b). The Wrist Joint. Retrieved May 7, 2016, from http://teachmeanatomy.info/upper-limb/joints/wrist-joint/

Technology, M. I. of. (2007). Normal Ranges of Joint Motion. Retrieved March 7, 2016, from http://web.mit.edu/tkd/stretch/stretching_8.html#SEC88

Teitel, A. D. (2013). Types of Muscle Tissue. Retrieved September 22, 2015, from https://www.nlm.nih.gov/medlineplus/ency/imagepages/19841.htm

The Physics Classroom. (2016). Mechanics: Work, Energy and Power. Retrieved November 12, 2016, from http://www.physicsclassroom.com/calcpad/energy

Tichauer, E. R. (1966). Some Aspects of Stress on Forearm and Hand in Industry. *Journal of Occupational and Environmental Medicine*. Retrieved from https://journals.lww.com/joem/Citation/1966/02000/Some_Aspects_of_Stress_on_Forearm_and_Hand_in.3.aspx

United Nations University. (2016). Techniques Available for Measuring Energy Expenditure. Retrieved from http://archive.unu.edu/unupress/unupbooks/80473e/80473E0f.htm

Widmaier, Eric P.; Raff, Hersel; Strang, K. T. (2010). Muscle. In *Vander's Human Physiology: The Mechanisms of Body Function* (12th ed., pp. 250–291). New York: McGraw-Hill.

Winter, D. A. (1991). *The Biomechanics and Motor Control of Human gait:normal, elderly and pathological*. Retrieved from http://www.clinicalgaitanalysis.com/teach-in/inverse-dynamics.html

Yoopat, P., & Vanwouterghetn, K. (2010). Biomechanical Risks in Thai Construction Workers. In *Ergonomics for All: Celebrating PPCOE's 20 years of Excellence: Selected Papers of the Pan-Pacific Conference on Ergonomics, 7-10 November 2010, Kaohsiung, Taiwan* (p. 283). CRC Press.

Zhang, X., & Chaffin, D. B. (2006). Digital Human Modeling for Computer-aided Ergonomics. *Interventions, Controls, and Applications in Occupational Ergonomics*, (October 2016), Chapter 10. Retrieved from http://www.mechse.uiuc.edu/research/xudong/Preprint/ChapterPreprint.pdf%5Cnpapers2

BIODATA OF STUDENT

AZIZUL RAHMAN BIN ABD AZIZ GS43628

+60179200671
azizulrahman86@gmail.com

He is a mechanical engineering background personal (Grad.Eng. BEM, Grad.Tech. MBOT, MHFEM, MIAENG) conduct the Ph.D. research at Universiti Putra Malaysia (UPM). His Ph.D. research was focused on ergonomics or human factor engineering research field. The research has evaluated detail index of the upper limb postures difference distinguished by kinesiology parameters. His first degree was from Universiti Malaysia Pahang (UMP) in Mechanical Engineering with Automotive Engineering field graduated in 2009. His master's degree is in manufacturing system engineering and was awarded in 2012 from the Faculty of Engineering UPM. His Ph.D. expedition started from September 2015 under a supervisory committee of Assoc. Prof. Dr. Siti Azfanizam Ahmad, Assoc. Prof. Dr. Faieza Binti Abdul Aziz, Assoc. Prof. Dr. Siti Anom Ahmad and Prof. Dr. Rosnah Mohd Yusuff. His Ph.D. research activities were accepted and funded by the short-term grant initiated by UPM graduate school. The first research finding was presented in World Research & Innovation Convention on Engineering & Technology 2016 (WRICET2016) in Langkawi regarding the elbow flexion kinesiology investigation. His next research discovery has been submitted and accepted at the 4th International Conference on Human Factors and Ergonomics in South-East Asia (SEANES 2016) on radioulnar joint pronation analysis. However, the presentation was not continued limited by certain internal factors. His final presentation of the research conclusion was delivered at the 4th International Conference on Mechanical, Manufacturing and Plant Engineering (ICMMPE 2018) in Melaka. The research upshot has been published in the Springer Lecture Notes in Mechanical Engineering Book Series (LNME) 2019. He has also contributed as a facilitator in STEM activity conducted by the Faculty of Engineering UPM. He succeeds his Ph.D. *viva voce* on 13th June 2019.

LIST OF PUBLICATIONS

Conference Proceedings (Presented):

Azizul Rahman Abd Aziz, Rosnah Mohd Yusuff, Siti Azfanizam Ahmad, Ali Ahmed Shokshk, S. A. A. (2016). Kinesiology Investigation of Elbow Flexion Postures using Human Digital Modelling Simulation for Potential Energy and Muscles Activity. In *World Research & Innovation Convention on Engineering & Technology 2016 [WRICET2016]* (pp. 75–79).

Azizul Rahman Abd Aziz, Siti Azfanizam Ahmad, Faieza Abdul Aziz, S., & Anom Ahmad, Ali Ahmed Shokshk, S. B. S. (2018). Wrist Twist Working Posture's Muscles Activity and Potential Energy Analysis Via Human Digital Modelling. In *4th International Conference on Mechanical, Manufacturing and Plant Engineering (ICMMPE 2018).*

Conference Proceedings (Accepted):

Azizul Rahman Bin Abd Aziz, Rosnah Binti Mohd Yusuff, Siti Azfanizam Binti Ahmad, A. A., & Shokshk, T. M. and S. A. B. A. (2016). Human Digital Modeling Analysis of Muscles Activity and Potential Energy for Radioulnar Joint Pronation Postures. In *4th SEANES International Conference on Human Factors and Ergonomics in South-East Asia (SEANES 2016)*.

Journal (Accepted)

Azizul Rahman Bin Abd Aziz, Rosnah Binti Mohd Yusuff, Siti Azfanizam Binti Ahmad, A. A., & Shokshk, T. M. and S. A. B. A. (2016). Human Digital Modeling Analysis of Muscles Activity and Potential Energy for Radioulnar Joint Pronation Postures. *International Journal of Technology (IJTech)*.

Azizul Rahman Abd Aziz, Siti Azfanizam Ahmad, Faieza Abdul Aziz, Siti Anom Ahmad, Ali Ahmed Shokshk, S. B. S. (2019). Wrist Twist Working Posture's Muscles Activity and Potential Energy Analysis via Human Digital Modelling. *Springer Lecture Notes in Mechanical Engineering*.

Journal (Sent)

Azizul Rahman Abd Aziz, Siti Azfanizam Ahmad, Faieza Abdul Aziz, Siti Anom Ahmad, Ali Ahmed Shokshk, S. B. S. (2019). Wrist Flexion Postures Diversity Analysis on Muscles Activity and Potential Energy Differences using Digital Simulation. *Applied Ergonomics*.

Journal (Published)

Azizul Rahman Abd Aziz, R. M. Y., & Siti Azfanizam Ahmad, Siti Anom Ahmad, A. A. S. (2018). Kinesiology Investigation of Elbow Flexion Postures using Human Digital Modelling Simulation for Potential Energy and Muscles Activity. *Journal of Engineering Science and Technology,* (Special Issue on WRICET2016), 9–16.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : FIRST SEMESTER 2019/2020

TITLE OF THESIS / PROJECT REPORT :

SIMULATION-BASED EVALUATION OF UPPER LIMB POSTURES ACROSS RANGE OF MOTION THROUGH MUSCLE ACTIVITY AND ENERGY EXPENDITURE

NAME OF STUDENT :

AZIZUL RAHMAN BIN ABD AZIZ

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.

2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.

3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as:

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for:

☐ **PATENT** Embargo from ______________ until ______________
(date) (date)

Approved by:

____
(Signature of Student)
New IC No/ Passport No.:

Date :

____
(Signature of Chairman
of Supervisory Committee)
Name: Assoc. Prof. Dr. Siti
Azfanizam Binti Ahmad

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]