MATEC Web of Conferences **90**, 01063 (2017) DOI: 10.1051/matecconf/20179001063
AiGEV 2016

Ergonomic study on human-powered vehicles

Mohd Azman Abdullah[1,2,*], *Mohamad Haziq* Abdul Rahman[1], *Muhammad Zakwan* Azis[1], *Shamsul Anuar* Shamsudin[1,2], *Faiz Redza* Ramli[1,2] and *Mohd Nizam* Sudin[1,2]

[1]Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya 76100, Durian Tunggal, Melaka, Malaysia.
[2]Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya 76100, Durian Tunggal, Melaka, Malaysia.

Abstract. In this paper, new methods for ergonomic analysis of cyclist for 4-wheel recumbent seat human-powered vehicle (HPV) are performed. An ergonomic index with fundamental formulation is developed in order to determine the level of comfortness during handling of the HPV. Basic reference of sitting postures are produced from three HPVs for 20 different individuals. All the dimensions, angles and measurements are recorded. The same individuals are required to sit on the three HPV models to evaluate their comfortness and ergonomic by observing the same dimensions, angles and measurements of leg and hand postures. The data is compared with reference comfort sitting ergonomic. This study is limited to a number of individuals which are the students of a university in Malaysia with age range from 20 to 24 years old. However, the ergonomic index can be expanded for Asian people and with some improvement in the parameters, it can be used for other countries. Derivation of ergonomic index and formulation in determining the comfort level and ergonomic of HPV. Using the ergonomic index, a new improved HPV can be developed. The index is also applicable with modification on several parameters in the formulation for other countries.

1 Introduction

The ergonomic study for human posture always deal with workplace and workstation where people spend six to ten hours working and maintaining the same posture for long period of time [1]. There are also different studies for different regions of people in the world. There are not many studies of ergonomic involving driver and cyclist in recumbent seat. Many of the designs for driver's seat are following the design for human posture during sitting. In performing an ergonomics studies, human variability is used as a design parameter. The term success in ergonomics is measured by improved productivity, efficiency, safety, acceptance of the resultant system design and improved quality of human life [2]. The ergonomics plays the significance roles in human. Ergonomics not only important in establishing smooth interaction in using these appliances (comfortable and effective operation), but also contributes to the harmony and symbiosis of humans, machines and environments. Ergonomics is useful practical science which helps us to

* Corresponding author: mohdazman@utem.edu.my

achieve safety, security and comfort and to maintain and improve our health. Thus, the domains it covers vary significantly [3].

In ergonomics, there are 3 major goals. The main purpose goal is to generate tolerable working condition which neglects any danger to human life or in others word is safety. The second goal is productivity. At this condition, to enhance system performance, one can design a system which improves performance affordances. The final goal is to operator satisfaction. Satisfaction and dissatisfaction may be understood only in the both operator's and user's needs are clearly understood. Different type of people have different level of expectations, and these vary substantially between countries and cultures [4]. Furthermore, ergonomics provide working conditions which are good enough and above the minimum required to ensure health and safety of the workforce. This is not simple as that, as the musculoskeletal complaints are minimized. Then, a comfortable, productive and satisfying office environment can be achieved. To design such an environment, it is necessary to consider not only furniture and equipment, but also the job design, lighting, noise, air quality, office landscaping and personal space [5].

Based on research, there are several factors that lead to physical stress and injury on workers' bodies especially if coupled with poor machine design, tool, and workplace design or the use of improper tools. A dramatic increase in musculoskeletal disorder (MSDs) began in the 1970s when these disorders increasingly appeared on companies' injury and illness logs [5]. Appropriate general methodology for such an approach, which might be applicable to the following types of projects; selecting a commercially available product for purchase, improving an existing product or system, designing a new product system, adapting an individual workplace, refurbishing a business or workplace, for instance, after automation and designing a complete plant [1]. In this study, the ergonomic is focused on the cyclist for 4-wheel recumbent seat human-powered vehicle (HPV) [6] is performed. Propulsive force and cycling performance are affected by internal biomechanical variables which involve factors related to force or torque development and power production. These factors can be manipulated by modify and alter the effective muscle force or torque or power generated and transmitted to the vehicle.

These factors include position of initial and final muscle length, change in muscle length, muscle moment arm lengths, force arm length, load imposed on muscle, resistance arm length, joint angles, muscle angle of pull, single or multi-joint muscles, muscle fiber type and arrangement. Manipulations of external mechanical factors are affected the changes and interactions occurring in the internal biomechanical variables resulting in propulsive force [7]. Constraints imposed upon a cyclist are involving external mechanical factors which are the structure of the vehicle and how power is transmitted to the vehicle. These factors include the seat-to-pedal distance, seat tube angle, seat height, pedal crank arm length, handlebar height, length, and position, cycling body position, orientation, and joint configuration, foot-pedal position and losses in power transmission due to friction.

Manipulating these variables will alter joint angle position, joint angle ranges, muscle length, resistance load, muscle mechanical advantage, and the ability to produce force, torque and power. Thus the interaction between the internal biomechanical factors with the external mechanical factors in resulting propulsive force will be a function of developing force, torque, and power for propulsion. However, changes in the shape and structure of a human powered vehicle (from manipulation of the external mechanical factors) should be considered because it will further increased complexity. The consideration not only on how it affect propulsive forces, but also how it affects the type of resistive forces encountered from the environmental factors, and the resulting interaction between these forces [8]. HPV needs ergonomics analysis to increase their safety, comfortable and performance of HPV.

Safety is one of the important factors that people will consider. Thus, from ergonomics analysis the HPV can increase safety for the driver. For example, HPV use recumbent seat position which is more safety compared to normal bicycle. Based on ergonomics analysis and study, the comfort of HPV can be increased. Ergonomics study can increase HPV performance so that the driver can reach maximum speed with low energy consumption. The recumbent position has become popular due to its reduced frontal area thus reduced aerodynamic drag if compared to the normal upright position. It is suitable for high performance human powered vehicles. The center of mass of the vehicle is positioned relatively low to the ground making the vehicle more stable and safer because of less distance to fall if a crash were to occur. Recumbent position more protective because the head is protected as compared to the upright position the head leads the body if thrown forward over the handlebars. There are many advantages on recumbent position which are improved the visibility of driver by keeping the oncoming road in the field if vision, reduce neck strain, comfortable, reducing likelihood of crotch pain and injury, gives rider firm support to push against while pedaling, reduces the strain on the lower back and wrist as compared to the normal upright position. However, recumbent position still has it disadvantages. It may not allow for peak power production and sustained aerobic performances as high as normal upright position can produce [8]. There are several locations on sitting postures that have comfort angle.

In ergonomics study, angle of comfort is important to reduce stress and musculoskeletal disorder (MSDs) of HPV riders. Range of comfort angle for head location is 0° to 15°, upper arm is -15° to 45°, elbow comfort angle is from 80° to 120°, hip comfort angle is from 95° to 120°, knee is from 95° to 135°, ankle is from 85° to 110° and back is from 10° to 30°. Based on study, the optimum angle for knee is 120° while for elbow is 115° [8]. In the previous study of ergonomic via survey, the study was performed on a driving simulator cockpit where the cockpit represents the actual driver posture during driving and slightly in recumbent position [9]. The ergonomic scores were studied based on the opinions of the participants including seat position, steering wheel position, gear knob position, pedals positions and height of the seat. The results from the study is reliable only for statistical approach and require a lot of participants for the survey.

In this study, ergonomic study is performed on a human-powered vehicle (HPV) which was fabricated previously [6]. The HPVs were fabricated based on constraints of design such as seat type, track and wheel base dimensions and number of wheels. The previously successful design and analysis for manufacture (DAFM) [6, 9-12] was implemented in order to fabricate the HPVs. Nevertheless, the ergonomic aspect never been considered neither in design stage nor in fabrication stage. Three number of HPVs are selected for the study (Figure 1 2 & 3) and 2 approaches are performed which are actual human posture measurements and rapid upper limb assessment (RULA). Based on these three methods, the ergonomics of the HPVs are discussed and concluded.

2 Methodology

2.1 Cyclist posture measurement

There are several locations on sitting postures that have comfort angle. In ergonomics study, angle of comfort is important to reduce stress and musculoskeletal disorder (MSDs) of HPV riders. All respondent measurement and HPV measurement will be used to calculate leg and hand angle of respondent. Figs. 1-3 show the position and angle of leg with hand of the respondent sit on HPV 1, HPV 2 and HPV 3. The angles (Figure 4) are calculated by using the formula in Eq. (1), (2) and (3) for leg and hand angle of the respondent. The ergonomic index formula is shown by Eq. (4). The percentage of error is calculated to determine the best HPV for each of the respondent. Each HPV will have its one ergonomic index for each respondent. This formula is used to determine which HPV is

DOI: 10.1051/matecconf/20179001063

suitable or more ergonomics for each respondent. The lower the percentage of error the higher percentage of ergonomic of the HPV. Therefore, this calculation is important to indicate the level of ergonomics of each HPV for each of the respondent. Each respondent will have their own calculation of angle, thus from this calculation will help to determine which HPV is the most ergonomics for each of the respondents.

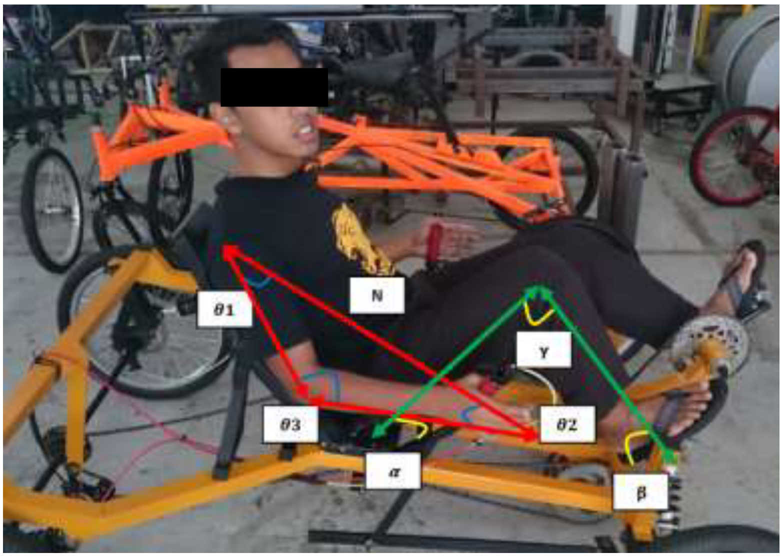

Fig. 1. Angles and measurements for respondent on HPV 1.

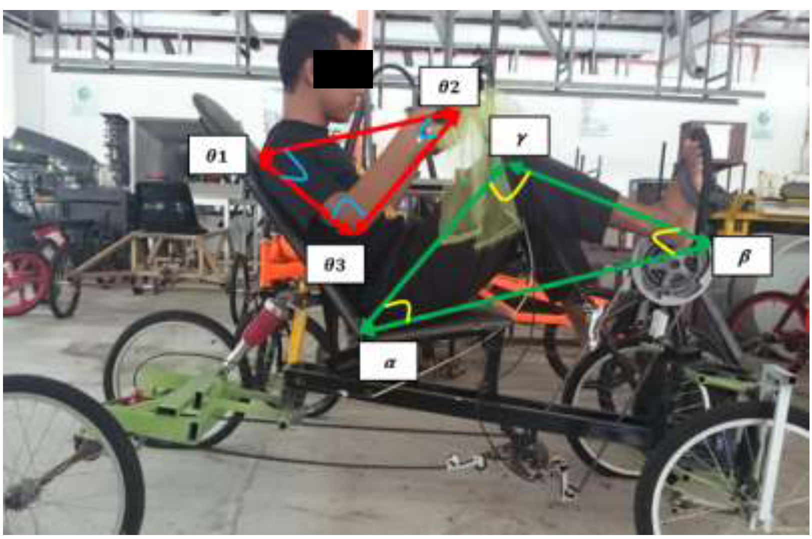

Fig. 2. Angles and measurements for respondent on HPV 2.

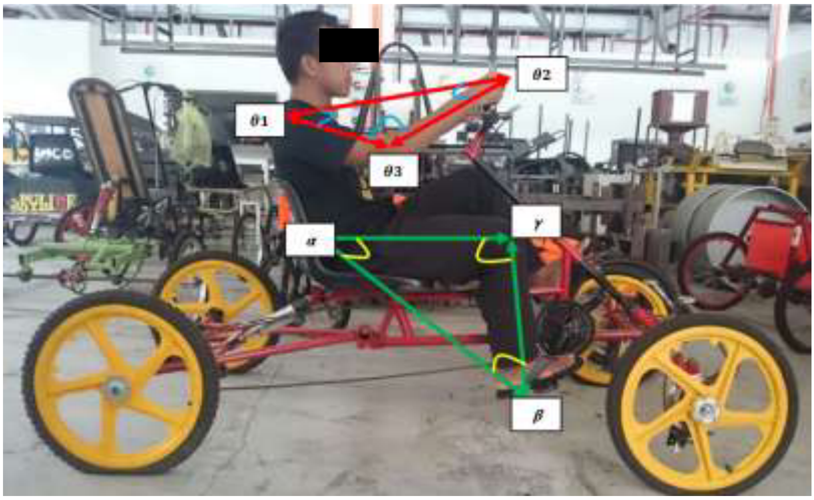

Fig. 3. Angles and measurements for respondent on HPV 3.

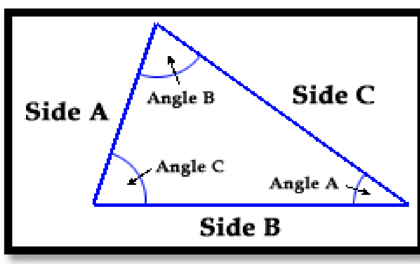

Fig. 4. Angles relation with dimensions.

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab} \tag{1}$$

$$\cos A = \frac{c^2 + b^2 - a^2}{2cb} \tag{2}$$

$$\cos D = \frac{b^2 - c^2 - a^2}{2ac}\ , B = 180° - D \tag{3}$$

$$Percentage\ of\ error = \left|\frac{Theory\ value - Experimental\ value}{Theory\ value}\right| \times 100 \tag{4}$$

2.2 Rapid Upper Limb Assessment (RULA)

RULA (Rapid Upper Limb Assessment) is two quick postural targeting methods for evaluating workers postures and finding risk factor index. It was used to evaluate postural risk factors on pediatric population of two age groups where the purpose was to investigate the inter-rater and intra-rater reliability of RULA. From the results, it shows that RULA was more reliable and practical while evaluating the older age group of children, but its level of reliability necessitates caution for its lone use while evaluating younger children [13]. The RULA was designed for easy use without need for an advanced degree in ergonomics or expensive equipment. Using the RULA worksheet, the evaluator will assign a score for each of the following body regions: upper arm, lower arm, wrist, neck, trunk, and legs. After the data for each region is collected and scored, tables on the form are then used to compile the risk factor variables, generating a single score that represents the level of MSD risk as shown in Table 1 below.

Table 1. RULA score.

Score	Level of MSD risk
1-2	Negligible risk, no action required
3-4	Low risk, change may be needed
5-6	Medium risk, further investigation, change soon
6+	Very high risk, implement change now

3 Results and discussion

Table 2-5 show the ergonomic index (percentage) for all 20 respondents. Based on Table 2-5, it indicates that the most ergonomics HPV for respondent 1 is HPV 3. Only 9.75 percentage of error for elbow angle compared to the optimum elbow angle. Thus, it leads others HPV, which are 37.71 and 24.60 percentage of error for HPV 2 and HPV 1 respectively. HPV 2 is the least in percentage of error for knee angle (6.54%) compared to others which are 10.32 and 13.45 percentage of error for HPV 1 and HPV 3 respectively. Therefore the most ergonomic HPV for all respondents is HPV 3.

Table 2. Percentage of error for respondent 1 (R1) to 5 (R5).

HPV	Part	Respondents Percentage of Error (%)				
		R1	R2	R3	R4	R5
1	Knee	10.32	15.18	15.11	23.20	16.57
	Elbow	24.60	27.79	38.30	36.83	12.74
2	Knee	6.54	3.60	3.73	1.04	2.79
	Elbow	37.71	35.42	45.06	41.28	26.57
3	Knee	13.45	11.02	11.18	7.07	10.35
	Elbow	9.75	10.75	11.33	22.47	10.67

Table 3. Percentage of error for respondent 6 (R6) to 10 (R10).

HPV	Part	Respondents Percentage of Error (%)				
		R6	R7	R8	R9	R10
1	Knee	17.95	15.01	4.06	2.07	3.87
	Elbow	38.96	35.24	37.28	29.31	34.51
2	Knee	2.10	3.89	10.82	12.34	11.10
	Elbow	44.21	41.68	44.04	43.85	34.51
3	Knee	9.83	11.36	17.17	18.55	17.49
	Elbow	19.89	17.01	18.68	3.14	14.58

Table 4. Percentage of error for respondent 11 (R11) to 15 (R15).

HPV	Part	Respondents Percentage of Error (%)				
		R11	R12	R13	R14	R15
1	Knee	15.11	21.39	8.38	12.08	16.86
	Elbow	44.55	32.36	38.71	1.21	40.11
2	Knee	3.73	0.01	20.08	23.00	27.00
	Elbow	34.33	46.40	55.32	1.33	45.84
3	Knee	11.18	7.89	25.36	27.98	31.71
	Elbow	17.34	27.32	37.25	3.77	32.62

Table 5. Percentage of error for respondent 16 (R16) to 15 (R20).

HPV	Part	Respondents Percentage of Error (%)				
		R16	R17	R18	R19	R20
1	Knee	5.98	4.08	15.32	8.35	5.98
	Elbow	34.41	37.85	32.73	38.44	34.16
2	Knee	9.50	10.79	3.37	20.04	9.50
	Elbow	41.26	49.44	44.92	49.17	52.68
3	Knee	16.02	17.14	10.75	25.32	16.02
	Elbow	25.31	31.70	32.73	37.04	30.85

Based on Fig. 5, it shows that the differentiation percentage of comfort for knee and elbow for each of HPVs. Percentage of comfort for HPV 1 is 88.16% and 67.5% of knee and elbow respectively. This briefly describes that the HPV is comfort for respondents knees, but not really comfort in terms of respondents elbow part. Next is HPV 2 and from the bar chart, we can see that percentage of comfort for HPV 2 is 90.75% and 59.25% of knees and elbows respectively. This briefly describes that HPV 2 is really comforting for respondents' knee but not really comfort in terms of respondents' elbow part. Lastly is the percentage of comfort for HPV 3 and from the bar chart, we can know that percentage of comfort for HPV 3 is 84.16% and 79.29% of knee and elbow respectively. This briefly describes that HPV 3 is really comforting for respondent knee and also comfort in terms of respondents elbow part.

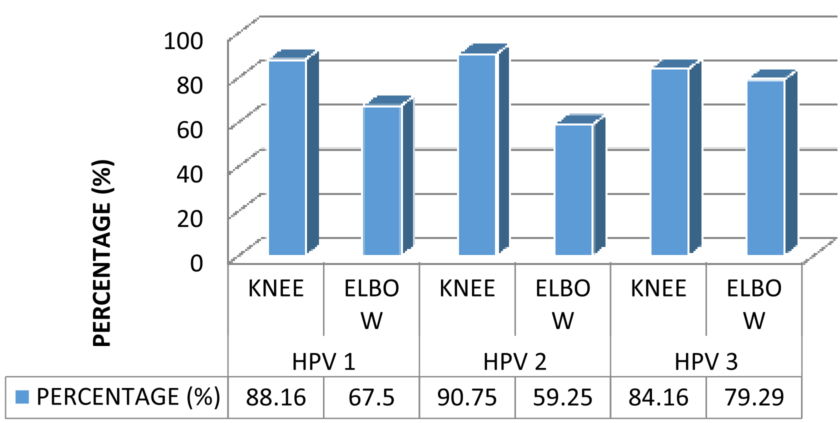

Fig. 5. Ergonomic index for each of the HPV for knee and elbow.

Results shown in Fig. 6-8 are from RULA analysis for ergonomic posture for all HPVs. The ergonomic score is 3 for all HPVs. From this ergonomic value, it shows that the design of all HPVs is acceptable in terms of ergonomic because nearly to the most ergonomic value in RULA analysis. As stated before, the most ergonomic value in a sitting position is two. RULA only evaluate the ergonomic factors based on the design of the HPVs not the actual HPVs. The ergonomic values for leg and upper arm are important. Forearm part ergonomic value is really closed to the most ergonomic value which is one. It is considered as good in terms of ergonomic since it gets two for ergonomic value for RULA analysis. Thus, all HPVs are ergonomic for cycling and handling based on their design.

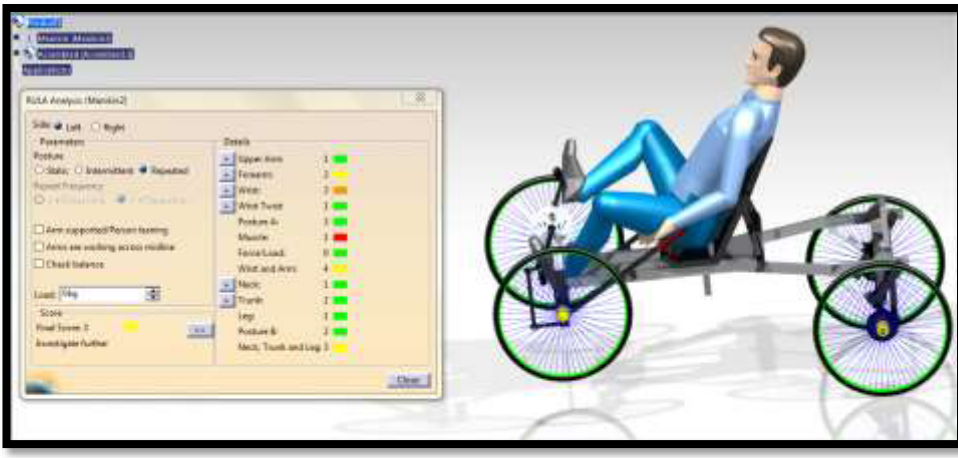

Fig. 6. RULA evaluation of HPV 1.

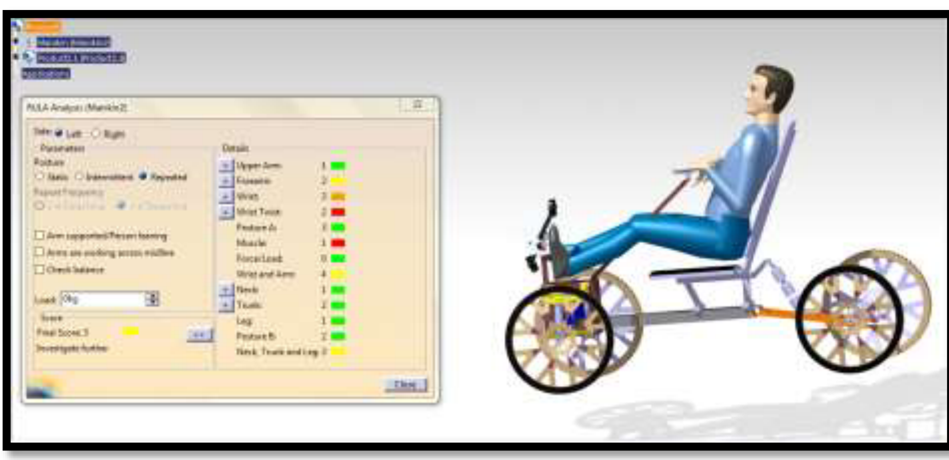

Fig. 7. RULA analysis of HPV 2.

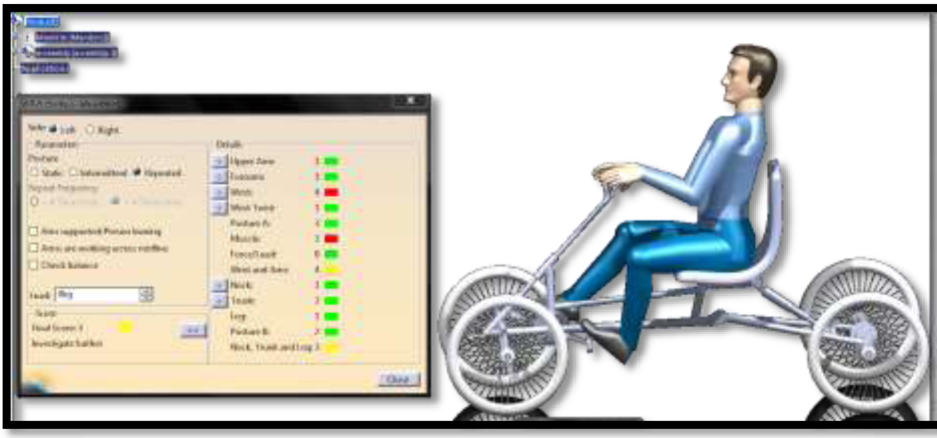

Fig. 8. RULA analysis of HPV 3.

4 Conclusions

Ergonomic index value analysis is used to determine the best HPV for all respondents. This was done through calculation of respondent angle and compared it with comfort angle in terms of ergonomic. High percentage of ergonomic index means high value in ergonomic aspect. RULA analysis is used to evaluate the HPVs in terms of ergonomic by the score. Low mark from RULA analysis indicate the excellent HPV design in terms of ergonomic. Based on the study, HPV 3 is the most ergonomic HPV among others. Even though HPV 1 and HPV 2 have high ergonomic index on knee, total score for ergonomic index (knee and elbow) goes to HPV 3. This method can be used for other design of recumbent type vehicle to evaluate its ergonomic index.

The authors gratefully acknowledged the Advanced Vehicle Technology (AcTiVe) research group of Centre for Advanced Research on Energy (CARe), the financial support from Universiti Teknikal Malaysia Melaka (UTeM) under Short Term Research Grant (PJP/2014/FKM (10A)/S01330).

References

1. B. W. Jan Dul, *Ergonomics for Beginners : a quick reference guide. (Third Edit)*, *Boca Raton: CRC Press Taylor & Francis Group*, (2008).
2. K. Kroemer, H. Kroemer, and K. Kroemer-Elbert, *How to design for ease and efficiency*, *Ergonomics, Prentice-Hall, New Jersey*, (2001).
3. S. E. Burt, & L. J. Fine, *Musculoskeletal Disorders and Workplace Factors*, *National Institute for Occupational Safety and Health*, (1997).
4. O. Korhan, *Work-Related Musculoskeletal Discomfort in the Shoulder due to Computer Use*, *North Cyprus, Mersin, Turkey*, (2012).
5. Occupational Health and Safety Council of Ontario, *Musculoskeletal Disorders Prevention Series*, Occupational Health and safety Council of Ontario (OHSCO), (2007).
6. M. A. Abdullah, S. A. Shamsudin, F. R. Ramli, M. H. Harun and M. A. Yusuff, *Design and Fabrication of a Recreational Human-Powered Vehicle*, *International Journal of Engineering Science Invention*, ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726, www.ijesi.org, Volume 5 Issue 2, February 2016, PP.11-14, (2016).

 DOI: 10.1051/matecconf/20179001063

7. D. Kee and W. Karwowski, *A comparison of three observational techniques for assessing postural loads in industry*, *International Journal of Occupational Safety and Ergonomics*, 13(1), 3–14, (2007).
8. A. R. Tilley, J. Anning, and R. Welles, *The Measure of Man and Woman: Human Factors in Design*, Revised Edition. *Wiley & Sons*, (2002).
9. M.A. Abdullah, A.H. Mohamad and F.R. Ramli, *Design Analysis and Fabrication of Fixed-Base Driving Simulator Frame*, *Journal of Engineering and Technology (JET)*, Penerbit Universiti, Universiti Teknikal Malaysia Melaka, Vol. 4, No. 2, July-December 2013, ISSN: 2180-3811, 85-101, (2013).
10. M. A. Abdullah, M. R.Mansor, M. Mohd Tahir, S. I. Abdul Kudus, M. Z. Hassan and M. N. Ngadiman, *Design, Analysis and Fabrication of Chassis Frame for UTeM Formula Varsity^{TM} Race Car*, *International Journal of Mining, Metallurgy & Mechanical Engineering (IJMMME)*, Volume 1, Issue 1, 75-77 ISSN 2320–4060 (Online), (2013).
11. M.A. Abdullah, M. R. Mansur, N. Tamaldin and K. Thanaraj, *Development of Formula Varsity Race Car Chassis*, *IOP Conference Series: Materials Science and Engineering*, Vols. 50, No. 1, doi:10.1088/1757-899X/50/1/012001, (2013).
12. M. A. Abdullah, N. Tamaldin, F. R. Ramli, M. N. Sudinand A. M. Mohamed Muslim, *Design and Development of Low Cost All-Terrain Vehicle (ATV)*, *Applied Mechanics and Materials, Trans Tech Publications*, Vols. 663, pp 517-521, doi:10.4028/www.scientific.net/AMM.663.517, (2014).
13. S. Dockrell, E. O'Grady, K. Bennett, C. Mullarkey, R. Mc Connell, R. Ruddy, S. Twomey and C. Flannery, *An investigation of the reliability of Rapid Upper Limb Assessment (RULA) as a method of assessment of children's computing posture*, *Applied ergonomics*, *43*(3), pp.632-636, (2012).