Analysis of motorcycle design toward female rider based on posture evaluation index (PEI) approached in virtual environment

M Rafi¹, Y H Putri², E Muslim³ and B N Moch⁴
¹,²,³,⁴Department of Industrial Engineering, Universitas Indonesia

E-mail: muhammad.rafi61@gmail.com yunika_ti06@yahoo.com erlinda@eng.ui.ac.id boymoch@eng.ui.ac.id

Abstract. This research examines the ergonomic aspect of motorcycle in virtual environment by using Jack software 6.1 with Posture Evaluation Index (PEI) approach which can integrates the results of three methods: Lower Back Analysis (LBA), Ovako Working Analysis (OWAS) and Rapid Upper Limb Assessment (RULA). The objectives of this research are evaluating the existing motorcycle design and determines the most ergonomic design that concern at handlebar height and distance between seat and handlebar. The result showed that the most ergonomic design of motorcycle for female rider is motorcycle that has 16cm handlebar height and 20cm distance between motorcycle’ seat and handlebar, which have 1.45 of PEI score.

1. Introduction

Nowadays, the cheap price, fuel-efficient, and easy maintenance of motorcycle makes the demand increase. In Indonesia, according to the data from Badan Pusat Statistik, the number of motorcycles has reached around 143,75 million units in 2019, ironically, Polda Metro Jaya recorded in 2019 that number of traffic accidents throughout Indonesia reached 190,000 accidents and 73.49% of the accidents involving motorcycle.

A motorcyclist requires more concentration than driver, beside that rider are also easier to feel tired, and this fatigue factor was mentioned as one of the factors causing the accident. New South Wales (NSW) Road Traffic Authority (RTA) noted that 5.4% of motorcycle accident victims are riders who are tired, where that percentage is significantly higher than other drivers who involved in accidents caused by tired driver. That accident data highlights the fact that fatigue is more dangerous to the safety of motorcycle rider than vehicle drivers.

There are several factors that potentially contribute to the fatigue experienced by motorcycle riders, one of these factors is vehicle factors [1]. Vehicle factors that direct contribute to fatigue are vibration and noise of motorcycle engines. In addition, they also noted that physical demands, such as posture and vehicle control, are also affected as well as the cognitive demands associated with vehicle operation which also contributed. When human is sitting, the load is 6-7 times much heavier than standing position. Atlas bone that supports the skull suffered the heaviest burden and when riding with the wrong position, the lumbar vertebrae of the spine (L2 and L3) will be suffered by low back pain, if it is happened continuously, it will arise inflammation (artrosis lumbar) and calcification if the spine and pinched their spinal cord and the worst it will get fractured [2]. Unfortunately, in Indonesia, the facts have not been followed by scientific research and related improvement. This is what then
underlies the need for research on motorcycle designs, especially the cub model. Humans have different body sizes and these differences will affect the dimensions of the body so that designers must consider several factors so that their product designs can be optimal. This study objective is to calculate the comfort level of female riders when riding a cub motorcycle.

2. Research Methodology
In general, ergonomics is a science that studies the relationship between humans and machine so can result an efficiency, convenience and security [3]. Therefore, the concept of ergonomics should be a basic framework for the development of a product design so that designs have value-added products which can enhance the benefits (tangible and intangible benefits) that will be felt by users of products, in this case consumers, and can meet their expectations, so they can give satisfaction to the users [4]. Customer satisfaction is a key influence on future buying behavior, consumers will make a choice based on their perception of value and satisfaction, where consumer satisfaction is a key to future purchasing behaviour [5].

In the ergonomics application, ideally, we must implement “to fit the job to the man” in the system work design, as well as in product design [6]. To be “fit to the man”, we need anthropometric data. Anthropometry is the study of human body size, where the variables and the measurements were standardized by ISO (International Standard Organization) as stipulated in the ISO DIS 7250 and Technical Committee 159. Those anthropometric measurements are grouped into three categories, that is structural anthropometric data (subjects measured in a static position), functional anthropometric data (subjects were measured during some particular movement) and Newtonian anthropometric data.

Man has different body size and those differences will affect the dimensions of the body so that the designer must consider several factors that can design an optimal product. Those factors that must be considered are age, gender, body position, disability, clothing, ethnicity, and pregnancy. There are two main principles when determining anthropometric data, that is extreme anthropometric data (percentile 1st, 5th, 10th, 90th, 95th, 99th) and average anthropometric data (percentile 50th) where the determination of the principle adapted to the purpose of the design itself.

Virtual environment or as known as virtual reality is an artificial physically representation that generated by a computer that enables users to interact with artificial environments that have similarities to the real environment [7]. Jack Human Modelling is a tool that uses a virtual environment [8]. Jack is an ergonomics and human factors product that allows the user to position the human biomechanical model accurately in a virtual environment, give the model a set of tasks to be performed, and analyze the performance of the task [9]. In this software, Jack has a Task Analysis Toolkit (TAT) that can help designers determine the ergonomics level of the products.

In this research, Posture Evaluation Index (PEI) is the evaluation methods that will be used. This method is used to optimize various geometric feature configurations at a work station [10]. This method was developed by Francesco Caputo, Prof; Giuseppe On Gironimo, Ph.D. and Adelaide Marzano, Ing., from the university of Naples Federico II, Italy. The first stage in this research is identifying the research variables and data. The second stage is processing data. In this stage, two processes are carried out, namely the simulation using Jack 6.1 software and the calculation of the PEI value. After determining the configuration, the next step is to make a motorcycle design based on the configuration using the Google Sketch Up software.

3. Result and Analysis
In this study, four types of data required, that is characteristic of women motorcycle riders, motorcycle specification (as a reference), woman’s anthropometric data and trajectory data. And then, that data is collected through questionnaire and observation. The posture of motorcycle riders is shown in Figure 1.
Figure 1. Sample posture of motorcycle riders

The data that derived from questionnaire contains characteristic of motorcycle driver and their trajectory. In rider characteristic, this research focused on several aspects that are considered important, such as driving time, weight of luggage, and road conditions. The results are shown in Figure 2.

Figure 2. Recapitulation of questionnaire results

Aside from collecting data through questionnaires, the authors also collected data through direct measurement. The data was obtained through direct measurement are specification of motorcycle and anthropometric data. Specification data is used to make motorcycle models that match with the actual size so it can present actual system. The specification of motorcycle is shown in Table 1.

| No | Component            | Dimension (cm) |
|----|----------------------|----------------|
| 1  | Handlebar            | 68             |
| 2  | Hand Grip            | 11             |
| 3  | Seat                 | 20             |
| 4  | Wheel Diameter       | 43             |
| 5  | Seat - Handlebar     | 30             |
| 6  | Footstep - Ground    | 21             |
Anthropometric data are also necessary to make a good analysis. The measurements are performed on women who aged 17 to 24 years where there is 13 measured body dimensions including weight and height. Average percentile principle (percentile 50th) is used because it is the midpoint of the bridge of range body size from maximum extreme value (percentile 95th) and minimum extreme value (percentile 5th). Besides that, average percentile is used for the consideration on the actual condition of motorcycle manufacturers, they would prefer to produce motorcycle with the highest market share (assumed that percentile 50th have >75% of the population). The anthropometric dimensions for each percentile are shown in table 2.

**Table 2. Anthropometric dimensions**

| No | Anthropometric Dimension | Percentile 5th | Percentile 50th | Percentile 95th |
|----|--------------------------|----------------|----------------|----------------|
| 1  | Body Height              | 151.7          | 157.5          | 164.65         |
| 2  | Body Weight              | 43.2           | 50.84          | 60.3           |
| 3  | Arm Length               | 68.3           | 71.2           | 74.7           |
| 4  | Tip of Elbow to Tip of Finger Distance | 40.8 | 42.4 | 44.5 |
| 5  | Shoulder & Elbow Distance | 32.8          | 34.3           | 36             |
| 6  | Hand Width               | 7.5            | 7.8            | 8              |
| 7  | Hand Length              | 16.7           | 17.4           | 18.2           |
| 8  | Femur Length             | 48.2           | 50.8           | 53.8           |
| 9  | Hip Width                | 31             | 33.4           | 35.9           |
| 10 | Foot Width               | 8.2            | 8.5            | 8.9            |
| 11 | Foot Length              | 22.6           | 23.5           | 24.6           |
| 12 | Ankle Height             | 5.7            | 5.9            | 6.1            |
| 13 | Knee Height              | 47.3           | 49.7           | 52.5           |

The second stage is processing the data. In this stage there are two processes, that is simulation using Jack 6.1 software and the calculation of the value of PEI. Before performing the simulation, first we must determine the model configuration that will be tested. The configurations are made of combination of seat and handlebar design vertically and horizontally, that will be simulated on the flat and bumpy trajectory.

After determining the configuration, the next step is make motorcycle design based on that configuration with Google Sketch Up, and then converted into .jt form by NX 6.0 software assistance. That design will be used as input in the simulation by using Jack 6.1 software. By using Jack software, we can analyze the value of static strength prediction (SSP), Lower Back Analysis (LBA), Ovako Working Posture Analysis (OWAS) and Rapid Upper Limb Assessment (RULA) from body posture that is used. The result of that value would be required input in calculating the value of PEI.

After the PEI values for all configuration obtained, the next steps are making some analysis and evaluation so a conclusion can be drawn from it. The motorcycle configurations are shown below in Table 3.

**Table 3. Motorcycle configuration**

| Configuration | Seat – Handlebar (Vertical) (cm) | Seat – Handlebar (Horizontal) (cm) | Road Condition | Status |
|---------------|----------------------------------|-----------------------------------|----------------|--------|
| Config 1      | 30                               | 26                                | Flat           | Actual |
| Config 2      | 30                               | 26                                | Lot of speed bump | Redesign |
| Config 3      | 30                               | 6                                 | Flat           | Redesign |
| Config 4      | 30                               | 16                                | Lot of speed bump | Redesign |
|               | 30                               | 36                                | Flat           | Redesign |
Process simulation with Jack 6.1 software done in several stage, such as:

- Creating a virtual environment that consisted of a motorcycle model and their trajectory,
- Create a virtual human based on anthropometric data collected,
- Make some position of virtual human on virtual environment accordance with the women rider posture obtained (shown in figure 3),
- Giving additional load on the virtual human. In this study, the force / load placed on the shoulder and neck, where both of that load presenting the bag and helmets load,
- Creating an animated series that can depicted the actual motorcycling activities,
- Running a virtual human simulation and analysis using Jack Analysis Toolkits.

Jack TAT that will be used in this study is the SSP, LBA, OWAS, and RULA. SSP is used to assess whether the simulated postures can be performed by at least 90% of the total population rider. LBA is used to analyze compression forces experienced by the spine and then compared with the NIOSH standard, which is 3400 N. Besides that, the LBA can also assess the possibility of spine injury. OWAS used to analyze the posture of the rider’s body as a whole and assess the possible risk of injury on musculoskeletal system. OWAS is a relative evaluation for any inconvenience experienced by a posture that caused by intensity of load. RULA is used to analyze upper limb that consists of arms, wrists, torso and neck. The virtual human positioning process is shown in Figure 3.
Figure 3. Positioning virtual human process

Jack’s recapitulations of the TAT analysis and PEI calculation value for each configuration can be seen in Table 4 below.

Table 4. Jack TAT analysis results

| Configuration | SSP >90% | LBA Speed Bump | OWAS Speed Bump | RULA |
|---------------|----------|----------------|-----------------|------|
|               |          | Flat           | Flat            |      |
| 1             | Yes      | 565            | 2               | 5    |
| 2             | Yes      | 1105           | 3               | 6    |
| 3             | Yes      | 501            | 2               | 3    |
| 4             | Yes      | 519            | 2               | 3    |
| 5             | Yes      | 1019           | 3               | 6    |
| 6             | Yes      | 468            | 2               | 3    |
| 7             | Yes      | 521            | 2               | 3    |
| 8             | Yes      | 542            | 2               | 3    |
| 9             | Yes      | 1347           | 3               | 7    |
| 10            | Yes      | 1341           | 3               | 7    |
| 11            | Yes      | 657            | 2               | 3    |
| 12            | Yes      | 946            | 3               | 7    |

From Table 4, we can see that all configurations have SSP values above 90%, the results indicate that postures that have been simulated by the virtual human can be performed by more than 90% of the rider population. The same with OWAS, all configurations have the values that tend same. It is because the rider’s body posture while riding tends to remain for each configuration. On the other
hand, LBA and RULA value for each configuration has value that fluctuates depending on the design used. Figure 4 shows the PEI values that obtained by each motorcycle design configuration.

![Comparison of Each Configuration with the Actual Design](image)

**Figure 4.** Comparison of configurations with the actual design

From Figure 4, it can be seen that the design $9^{th}$ which has a handlebar 6cm tall and 40 cm distance between seat and handlebar generate greater PEI value than the actual motorcycle design that is 2.57 for flat trajectory and 2.62 for bumpy trajectory. This shows that the design $9^{th}$ was not an ergonomics motorcycle. On the other hand, the smallest PEI values generated by design $6^{th}$ which has handlebar height 16 cm and 20 cm distance between seat and handlebar, that is 1.45 for flat trajectory and 1.77 for bumpy trajectory. This PEI has smaller value is due to rider posture, on a motorcycle while riding this configuration, tend to erect so the risk of injury that may occur in the spine and musculoskeletal system are relatively small.

4. **Conclusion**

PEI is a method that can assess whether the postures that occur when humans interact with a product meets standard ergonomics or not. PEI value that has been generated would reflect how much ergonomics that a product has, where the smaller PEI value produced more ergonomically product. Due to the ergonomics have some goals that is safety, convenience and efficiency so this study has the same goals too that is to reduce the fatigue experienced by riders in order to reduce accidents that occur. In this study, the characteristics of ergonomics are described on quantitatively by PEI value which have been calculated where the maximum value of this PEI is 3.42.

This study underlined three categories. The first configuration is the actual motorcycle design (H S X), where after it is simulated by using Jack 6.1 software we obtained 501 N LBA, this value still are regarded within safe limits because it didn’t pass compression action limit that has been standardized or equal to 3400 N so it is estimated have small risk of injury to the spine while riding relatively. Meanwhile, this design generated 2 for OWAS value in flat trajectory and 3 for bumpy trajectory. This showed that the current posture potentially could significantly endangered human musculoskeletal system so corrective action are needed as soon as possible. This design generated 5 for RULA value so it means that investigation and changes are needed as soon as possible. PEI value for this design is 1.68 for flat trajectory and 2.01 for bumpy trajectory. This number is not the best value of all configurations, so the chances to make improvement still wide opened potentially.
The second configuration is design 9\textsuperscript{th}, which is the worst configuration in terms of ergonomics side for women rider (percentile 50\textsuperscript{th}) based on PEI approached. This configuration has 6 cm handlebar height and 40 cm distance of seat – handlebars horizontally that generated 2.57 for flat trajectory and 2.62 for bumpy trajectory.

The third configuration is design 6\textsuperscript{th}, which is the best configuration in terms of ergonomics side for women rider (percentile 50\textsuperscript{th}) based on PEI approached. This configuration has 16 cm handlebar height and 20 cm distance of seat – handlebars horizontally that generated 1.45 for flat trajectory and 1.77 for bumpy trajectory.

When we see from differences between those three configurations, there are several key factors that affect the PEI value on women riders when riding that is the handlebar position, distance between seat and handlebar and the track condition. There is the tendency that the distance between seat and handlebar are getting closer (with range between 20 to 25 cm) would make lower PEI value while the distance between seat and handlebar are further away will create greater PEI value. If we want to make an optimal motorcycle design, we must combine proximity distance between seat and handlebar with handlebar height which ranges 16 to 36 cm.

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