The Design of Rowing Ergometer Based on the Anthropometry of Acehnese Male Athletes

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Abstract. A rowing athlete requires effective and systematic physical training. Thus, an ergometer is very influential on the endurance of an athlete's body and becomes a vehicle of simulating groundwater rowing. However, the ergometer tool currently used has no specifications and dimensions that are in accordance with the anthropometry of male rowing athletes in Aceh. Based on these conditions, the rowing ergometer tool will be designed based on the anthropometry of rowing athletes in Aceh. Data retrieval was done by taking samples from six male rowing athletes. The data were then tested for the level of trust, accuracy, uniformity, and adequacy. From the results of data analysis, the design of the ergometer tool was in accordance with the anthropometry of male rowing athletes in Aceh. This situation can build comfort for male athletes and increase the endurance of their muscles. This includes maintaining the tempo of rowing and being able to move oars with long distances in a short time.

1. Introduction
Rowing is an activity that is technically, physically demanding and requires a sequence of coordinated actions by utilizing most of the muscle groups in the body \cite{1}. To achieve a rhythmic and harmonious movement, it needs to be supported by biomotoric quality, biometrics, psychology, and other supporting aspects \cite{2}.

Rowing is one of the sports that have developed in Indonesia, especially in Aceh. Acehnese male rowing athletes are trained to foster physical conditions for maximum achievement but have not found satisfactory results from the training and coaching \cite{3}. The important exercise factors are technical, tactical, physical and mental factors. Of the four factors, the physical factor is the most important in all sports, so a planned and systematic training program is needed. Moreover, in systematic training, the athletes are trained to form pattern movement and angle while they row. This is so that the constant speed can be achieved in the rowing process \cite{4}.

From the explanation above, the author assumes that a rower athlete must have good endurance to be able to maintain the tempo of rowing. Considering the rowing sports must be carried out in rivers, lakes, or calm seas, it is certainly very risky if there is a strong current or rain. To overcome this, the rowers had to do training in the room using a simulation machine, which is commonly called the rowing ergometer machine.
Research has shown that the ergometer is the right training device, considering the value of a higher grip strength when rowing [5]. However, existing ergometer devices are not designed based on the shape and size of Indonesian athletes, especially Acehnese athletes from Aceh, one of the provinces in Indonesia. This becomes the foundation of conducting this research. In this study, the researchers designed a rowing ergometer tool kit taking into account the influence of the anthropometry of the Acehnese rowing athletes.

This study aims to design rowing ergometer devices and determine the effect of the Acehnese male athletes’ anthropometry on the design of the ergometer devices. The output of this study is hoped to have the athletes be comfortable when using their sports’ tools so that they increase the endurance of their muscles to maintain the tempo of rowing and move the oars in long distances in a short time.

2. Literature review

2.1. Rowing ergometer

The ergometer is designed by adapting rowing movements in water, but this activity is carried out on land. This tool serves to simulate the action of rowing in water and becomes a training tool that is fast and easy. Generally, the friction contact forces on the ergometer occur between flywheels that use air such as in Figure 1 (a) or water that moves the opposite as appeared in Figure 1 (b). The user pulls a rope that rotates the loading system with an intermediary tool i.e. pulleys, just like rowing in the water. Thus, the value of strength and speed on the pulley’s spinning wheel is obtained by using a measuring instrument [6].

![Figure 1](image)

The ergometer that is currently available still has some disadvantages, especially in its dimensions. The dimensions of the ergometer in the market today are not designed based on the anthropometry of the Asian population, especially Indonesians, which generally has smaller postures. Thus, users of rowing ergometers in Indonesia, especially in Aceh, get several obstacles during its usage.

2.2. Anthropometry

Anthropometry is a field of study about humans that deals with measurement, especially in measuring the body, shape, strength, and work capacity [8]. It is a collection of numerical data that deals with the physical characteristics of the human body, namely the size, shape, and strength, and application of the data for handling design problems [9]. Many studies have used anthropometry in designing sports tools and various equipment that are essential to humans’ needs. Among the studies is the design of sepak takraw balls [10], exoskeleton to assist in manual lifting [11], headgear for soccer players [12], dynamometer for cutting forces [13] and even chairs [14].

Anthropometric measurements obtained from measurements are applied in terms of the design of rowing ergometer devices as discussed in this study. The results of studies in anthropometry can
determine the shape, and the exact dimensions related to the product that will be designed according to the humans who will use the product [15].

2.3. Anthropometry dimension

According to Irdiastadi and Yassierli [16], the anthropometric database is the main source of information needed for design. There are 17 dimensions of user anthropometry that are closely related to determining the shape and dimensions of a rowing ergometer tool shown in Figure 2.

![Anthropometric dimensions measured in the sample](image)

**Figure 2.** Anthropometric dimensions measured in the sample [17].

Meanwhile, Table 1 shows the 17 dimensions to be measured from a human body to obtain anthropometric data.

| No | Dimension             | No | Dimension             |
|----|-----------------------|----|-----------------------|
| 1. | Upright body height   | 10.| Hip width              |
| 2. | High waist standing   | 11.| Future reach           |
| 3. | Knee height standing  | 12.| Long forearm           |
| 4. | Sitting shoulder height| 13.| Long upper Arm         |
| 5. | Eye height sitting    | 14.| Hand width             |
| 6. | Sitting height        | 15.| Length of the palm     |
| 7. | Buttock knee          | 16.| Leg width              |
| 8. | Popliteal height      | 17.| Foot length            |
| 9. | Shoulder width        | 10.| Hip width              |

2.4. Determination of anthropometry and normal distribution data

Based on statistics, the size of humans in a population is around the average size, and a small portion of the sizes is on the two sides of the distribution. This implies that about 50% of the user population
can use the results of the design properly. While the remaining 50% cannot use the design properly; and this design is based on an average concept only [18].

Normal distribution methods are commonly used in establishing anthropometric data. Then, the percentile determination can be done with a normal distribution table. The 95-th percentile size anthropometry will show the "largest" body dimension and the 5-th percentile describes the "smallest" body dimension [19].

2.5. Data testing
To realize a product design that has flexibility and "capable of conformity" with a certain size range, it is necessary to obtain the right anthropometric data. Consequently, it is necessary to test anthropometric data to determine the correctness of this data. The following are the stages in testing anthropometric data:

a. Level of trust and level of accuracy
   The level of trust displays the value of the belief of a researcher that the results of the calculations obtained to meet the requirements of accuracy. While the level of accuracy describes the highest deviation from the measurement results that are understood by researchers.

b. Data uniformity test
   Test of data uniformity is a stage in statistics that aims to obtain a certain level of confidence in the data and shows that all are within the control limit. The data uniformity test serves to minimize the variety of existing data by removing extreme data or data that is outside the control limits [20].

   The steps in the data uniformity test are determining the average, standard deviation, upper control limit (UCL) and lower control limit (LCL).

   To determine the average of the data set, Equation 1 is used

   \[ \overline{X} = \frac{\sum X_i}{n} \]  
   (1)

   Where:
   \( \overline{X} \) = Average data from observations
   \( X_i \) = Data on the measurement results of \( i \)
   \( n \) = The number of numbers observed

   In determining the standard deviation, Equation 2 is used.

   \[ \sigma = \sqrt{\frac{\sum(x_i - \overline{X})^2}{n - 1}} \]  
   (2)

   Where:
   \( \sigma \) = Standard deviation
   \( x_i \) = Results of measuring data

   To get the UCL and LCL, Equations 3 and 4 are used.

   \[ UCL = \overline{X} + k(\sigma) \]  
   (3)

   \[ LCL = \overline{X} - k(\sigma) \]  
   (4)

   Where:
   \( k \) = Coefficient of confidence level

   a. Test the adequacy of data
   In this study, testing the adequacy of data was used to test the data taken as sufficient or not by knowing the value of \( N' \). If the value of \( N' \leq N \), then the data measurement result is said to be
sufficient and no data collection is needed anymore. The following are the test steps for data sufficiency by using Equation (5)[20].

\[
N' = \frac{k}{\sigma} \sqrt{\frac{N}{\sum_{i=1}^{n} x_i^2} - \frac{(\sum_{i=1}^{n} x_i)^2}{\sum_{i=1}^{n} x_i}}
\]  

(5)

Where:
- \(N'\) = Number of observations that must be done
- \(x_i\) = Results of i-size data
- \(s\) = The level of accuracy that should be
- \(k\) = Coefficient of confidence level

2.6. Determining percentile values

The standard deviation and mean must be done first to determine the percentile value as the basis for the design of this ergometer device; 95-th for the large percentile size, 50-th for the average and 5-th percentile size for the small percentile size. Equation (6) is used to determine the dimension value of the specified percentile [20].

\[
X = \bar{X} \pm Z \sigma
\]  

(6)

Where:
- \(X\) = Value for the selected percentile
- \(\bar{X}\) = Average value
- \(Z\) = Constants for the selected percentile
- \(\sigma\) = Standard deviation

3. Methodology

Preliminary data collection for design considerations was carried out at the Krueng Lamnyong Edge Rowing Training Center, Banda Aceh, Indonesia.

3.1. Data collection design

In designing this rowing ergometer tool to obtain the required data, the researcher carried out anthropometric data collection on six Acehnese male rowing athletes. Males were chosen because, at the moment, only male athletes are available. This is by using the field research techniques that are done directly in the field to obtain anthropometric data from the samples by physical measurements.

3.2. Identification of athlete’s anthropometry

In general, there are 36 measuring parameters of the human body. But in this study, only 17 parameters were used (see Table 3) because they have large influences on the design of this rowing ergometer. Anthropometric data processing uses the concept of percentiles.

| Dimension | Information                  | Dimension | Information     |
|-----------|------------------------------|-----------|-----------------|
| D1        | Upright body height          | D10       | Shoulder width  |
| D2        | High waist standing          | D11       | Hip width       |
| D3        | Knee height                  | D12       | Knee-length     |
| D4        | Sitting height               | D13       | Popliteal height|
| D5        | Eye height sitting           | D14       | Hand width      |
| D6        | Sitting shoulder height      | D15       | Hand length     |
| D7        | Long upper arm               | D16       | Leg length      |
| D8        | Long forearm                 | D17       | Leg width       |
| D9        | Forward reach                |           |                 |
3.3. Data processing
The description of the research design process begins with the collection of anthropometric data for the Acehnese male athletes. Then, data processing was done by testing data to determine the level of accuracy and trust, data uniformity test, and test data adequacy. Afterward, determining the concept of percentiles so that the anthropometric data taken can be a reference in determining the concept of rowing ergometer tool design.

4. Results and discussion
4.1. Anthropometry data
Anthropometric data is needed so that the ergometer tool to be designed has a size that fits the users, in this case, the Acehnese rowing athlete. With 17 measurement criteria to be taken according to the design requirements as displayed in Table 4.

| No. | Dimensions measured                  | Measurement Subject |
|-----|--------------------------------------|---------------------|
| 1.  | Seated Height                        | 93.5 93.8 86 84.5 92 84.3 |
| 2.  | Eye Height Sitting                   | 82.5 82.3 71.9 74.5 80.5 71.3 |
| 3.  | Sitting Shoulder Height              | 61 62.8 59.2 60.5 61 58 |
| 4.  | Long Upper Arm                       | 37 41 35.7 39 37 34.9 |
| 5.  | Long forearm                         | 48.7 45.3 43.3 45.3 48.7 43 |
| 6.  | Popliteal Height                     | 45 45.9 46.8 44 45.8 47 |
| 7.  | Buttock knee                         | 58 58.7 53 53.6 57.8 63 |
| 8.  | Shoulder Width                       | 35.8 36 38.7 40.1 36.8 40 |
| 9.  | Hip width                            | 35.1 32.3 32 30.4 35.7 32 |
| 10. | Upright Body Height                  | 174.1 174.5 163.8 164 173.6 156.1 |
| 11. | High Waist Stand                     | 98 100.9 87 93 97 86 |
| 12. | Knee Height Standing                 | 48.5 48.3 43.8 47 47 43 |
| 13. | Future reach                         | 85.7 87.5 77 84.3 85.7 75 |
| 14. | Hand Width                           | 8.8 9.5 9.5 8.7 8 9 |
| 15. | Length of the palm                   | 18.5 20.4 18.2 19.4 17.8 17 |
| 16. | Foot Length                          | 26.5 27.5 24.5 24.6 27.5 24 |
| 17. | Leg Width                            | 7.1 7.8 7.5 7.5 7.1 7.6 |

4.2. Anthropometry data uniformity test
Calculation of data uniformity test in the design of this rowing ergometer tool uses the Excel program by using data obtained from direct measurements of the anthropometry of Acehnese male athletes (see Table 4). Processing is carried out repeatedly when there is data that passes the lower control limit (LCL) and upper control limit (UCL) when testing.

From the test results, uniform information from the overall uniformity test on 17 anthropometric dimensions of Acehnese male athletes are shown in Table 5.

| No | Dimensions                | Symbol | X       | σ       | UCL     | LCL     | Description |
|----|---------------------------|--------|---------|---------|---------|---------|-------------|
| 1  | Upright Body Height       | TBT    | 167.68  | 6.383   | 180.45  | 154.92  | equal       |
| 2  | High Waist Stand          | TPB    | 91.15   | 8.100   | 107.35  | 74.95   | equal       |
| 3  | Knee Height Standing      | TLB    | 46.27   | 1.911   | 50.09   | 42.44   | equal       |
| 4  | Seated Height             | TD     | 89.02   | 4.083   | 97.18   | 80.85   | equal       |
| 5  | Eye Height Sitting        | TMD    | 77.17   | 4.600   | 86.37   | 67.97   | equal       |
| 6  | Sitting Shoulder Height   | TBD    | 60.23   | 1.45    | 63.15   | 57.32   | equal       |
4.3. Data adequacy test

The next stage of processing anthropometric data is testing the adequacy of data. In doing so, the confidence level used is 95% and the figure level of accuracy is 5%. Table 6 shows the results of testing adequacy.

| No. | Measurement                | N  | N’ | Description (N’≤N) |
|-----|----------------------------|----|----|--------------------|
| 1   | Upright Body Height        | 6  | 3  | Adequate           |
| 2   | High Waist Stand           | 6  | 6  | Adequate           |
| 3   | Knee Height Standing       | 6  | 4  | Adequate           |
| 4   | Seated Height              | 6  | 4  | Adequate           |
| 5   | Eye Height Sitting         | 6  | 6  | Adequate           |
| 6   | Sitting Shoulder Height    | 6  | 1  | Adequate           |
| 7   | Long Upper Arm             | 6  | 6  | Adequate           |
| 8   | Long forearm               | 6  | 4  | Adequate           |
| 9   | Future reach               | 6  | 5  | Adequate           |
| 10  | Shoulder Width             | 6  | 4  | Adequate           |
| 11  | Hip width                  | 6  | 5  | Adequate           |
| 12  | Buttock popliteal          | 6  | 5  | Adequate           |
| 13  | Popliteal Height           | 6  | 1  | Adequate           |
| 14  | Hand Width                 | 6  | 5  | Adequate           |
| 15  | Length of the palm         | 6  | 6  | Adequate           |
| 16  | Foot Length                | 6  | 5  | Adequate           |
| 17  | Leg Width                  | 6  | 2  | Adequate           |

4.4. Percentile calculation

In the design of this rowing ergometer device, a 95-th percentile was used for large percentile size, 50-th percentile for average percentile size, and 5-th percentile for small percentile size. Table 7 shows the percentile size used in data.

| No. | Anthropometry     | Dimension | Percentile (cm) |
|-----|-------------------|-----------|-----------------|
|     |                   |           | 5-th | 50-th | 95-th |
| 1   | Upright Body Height| D1        | 157.2 | 167.6 | 178.1 |
| 2   | High Waist Stand  | D2        | 85.4  | 91.1  | 101.8 |
| 3   | Knee Height Standing| D7      | 43.1  | 46.2  | 49.4  |
| 4   | Seated Height     | D3        | 82.3  | 89    | 95.7  |
| 5   | Eye Height Sitting| D4        | 69.6  | 77.1  | 84.7  |
Table 7 shows the calculation obtained in the 5th, 50th, and 95th percentiles of each body dimension related to the design of the rowing ergometer tool. These values were the basis to determine the dimensions of the rowing ergometer tool for the Acehnese male athletes.

4.5. Determining the dimensions of the rowing ergometer tool
Based on calculations of the Acehnese male athletes’ anthropometric data percentile, the next step was to determine the dimensions of the parts of this ergometer tool. The dimensions of the ergometer are presented in Table 8.

| No. | Body size            | Rowing Ergometer Tool Dimensions | Percentile | Design Size (cm) |
|-----|----------------------|----------------------------------|------------|-----------------|
| 1.  | Upright Body Height  | Tool Length                      | 95         | 178.15          |
| 2.  | High Waist Stand     | Distance Between Leg Chairs with Chairs | 95         | 101.82          |
| 3.  | Knee Height Standing | Distance Between Seats with Leg Chairs | 95         | 49.40           |
| 4.  | Seated Height        | Tool Height                      | 95         | 95.71           |
| 5.  | Eye Height Sitting   | Height of Strength Indicator     | 5          | 69.62           |
| 6.  | Sitting Shoulder Height | Grip Height                  | 5          | 58.43           |
| 7.  | Long Upper Arm       | Distance to the user's body      | 5          | 34.31           |
| 8.  | Long forearm         | Distance to the user's body      | 5          | 41.67           |
| 9.  | Future reach         | Distance to the user's body      | 5          | 75.39           |
| 10. | Shoulder Width       | Handle Length                    | 95         | 40.69           |
| 11. | Hip width            | Chair Length                     | 95         | 35.62           |
| 12. | Buttock popliteal   | Seat Width                       | 50         | 57.35           |
| 13. | Popliteal Height     | Seat Height                      | 50         | 45.75           |
| 14. | Hand Width           | Handle Size                      | 95         | 9.60            |
| 15. | Length of the palm   | Handle Size                      | 5          | 16.99           |
| 16. | Foot Length          | Leg Length                       | 95         | 28.06           |
| 17. | Leg Width            | Foot Mount Width                 | 95         | 7.80            |

4.6. Design result
From the anthropometric data obtained, the dimensions of the ergometer tool were determined. By using the 2018 Autodesk Inventor Professional software, the design is finally constructed based on the anthropometric data of the Acehnese male athletes (see Figure 3). The size of the ergometer is based on the Acehnese anthropometry.
5. Conclusion
From the implementation of the research and design, several conclusions are drawn:
1. There are 17 anthropometric dimensions of Acehnese male rowing athletes that influence the design of this ergometer tool. Anthropometric data were taken from a sample of six male rowing athletes who represented the population of rowing users.
2. For data analysis, testing the adequacy test, data uniformity, and determination of percentiles as the basis of the design were conducted. From the test results, the seventeen anthropometric dimensions revealed uniform data and can be said to be sufficient through testing the adequacy of data. The 95-th, 50-th, and 5-th percentiles were found as shown in Table 7.
3. The results of determining the percentile value were used to design the ergometer tool, as presented in Table 8. The product design of the rowing ergometer tool is displayed in Figure 3.
4. Despite the design of the rowing ergometer tool was accomplished in this research, some limitations were found during this research and are expected to be considered by future researchers. First, data were only taken from male athletes, and thus, if women rowing athletes decides to participate in this sport in the future, another research to obtain their anthropometric data should also be conducted to design a rowing ergometer tool suitable for the females. Second, this research used a manual loading system, hence, future research should consider using the automatic loading system to add loading variation on the athletes while collecting data.

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