



DEVELOPMENT OF BI-MODAL EXERCISE BICYCLE FOR PHYSICAL FITNESS AND REHABILITATION

O. P. Fidelis^{1,4,*}, A. O. Falola^{2,4}, D. O. Odebiyi³ and E. O. Nwoye⁴

¹DEPT OF BIOMEDICAL TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, ONDO STATE, NIGERIA

²BIOMEDICAL ENGINEERING SERVICES, LAGOS UNIVERSITY TEACHING HOSPITAL, IDI-ARABA, LAGOS STATE, NIGERIA

³DEPARTMENT OF PHYSIOTHERAPY, UNIVERSITY OF LAGOS, AKOKA, LAGOS STATE, NIGERIA

⁴DEPARTMENT OF BIOMEDICAL ENGINEERING, UNIVERSITY OF LAGOS, AKOKA, LAGOS STATE, NIGERIA

Email addresses: ¹ opfidelis@futa.edu.ng, ² damolafalola@hotmail.com, ³ enwoye@unilag.edu.ng,

⁴ dodebiyi@unilag.edu.ng

ABSTRACT

Exercise bicycles are used for kinesiological activities; to increase general fitness, and for training for cycling events. They are also used for weight loss. The aim of this study is to produce a special exercise bike which allows for both upper and lower limbs pedalling either independently or otherwise. The manufacturing processes employed in the design involved the use of AutoCAD design suite and other production engineering processes which included material selection and acquisition, cutting, welding and drilling. The device was tested for both comfort and effectiveness for cardiac rehabilitation using the rate of heartbeat as the test parameter. A strong positive correlation was found ($p < 0.001$; $r = 0.962$) between the two heart rate tests. An ergonomic evaluation of the bi-modal exercise bike showed 98% suitability of the seat-pedal height with the knee height of the study population and 100% suitability of the seat-handle post height with the buttock-knee length of the population. In conclusion, the goal of developing a bi-modal exercise bike that permits simultaneous upper and lower limbs pedalling was realised.

Keywords: exercise bicycle; cycling; ergometer; fitness; rehabilitation.

1. INTRODUCTION

Physical activities are beneficial for controlling body weight, reducing the chances of heart diseases, reducing the risk of diabetes and some other chronic diseases by improving the functions of the heart, lungs and improving the biomechanical system of the body [1]. Aside surgery and medication, several methods have been proposed for the prevention and treatment of heart conditions. One of such methods is the use of regulated and supervised exercise as therapy both for prevention of heart conditions and following medication or surgery [2].

Some of the significant benefits of exercise have been reported to include improved body mass index (BMI), improved insulin levels and fitness [3], improved conditions in type II diabetes [4], as well as cardiopulmonary and muscular strength [5] in people with spinal cord injury. Exercise has also been reported to reduce posttraumatic stress disorder [6].

A physical exercise is definitely beneficial to many people when it is performed intelligently and with

proper medical guidance. Some of these benefits include reduction in the course of diseases, prevention of conditions such as obesity, diabetes, and hyperlipidaemia which are common causes of heart diseases. Exercise also lowers heart rate over time, increases maximal oxygen uptake (VO_{2max}) in the body, muscle strength, stroke volume and sub maximal working capacity. It helps in the restoration of normal functions in the case of cardiac rehabilitation, as well as the regulation of hormones [7-9].

The equipment used for fitness training and cardiac rehabilitation present many advantages for a cardiac patient and for healthy people who wish to avoid heart problems or wish to burn fat and loss weight [9]. One of such equipment is the exercise bicycle also called bicycle ergometer. Exercise bicycles are used for weight loss, to increase general fitness, and for training for cycle events [10]. There exist many types of exercise bicycles: those in recumbent positions, spinning machines – which are stationary bicycles built for spinning classes – standard ergometer and active

*Corresponding author, tel: +234 – 803 – 819 – 3799

passive trainer [11]. These bikes come with different mechanisms for adjusting the resistance to the pedals, thus, adjusting the intensity of exercise.

Since cycling is similar to walking [12], it can serve as a rehabilitation technique for the restoration of walking ability in patients who are recovering from stroke [13]. These similarities exist in form of reciprocal flexion and extension movements of hip, knee, and ankle; and present alternating and coordinated antagonist muscle activation [11].

Pedalling an exercise bicycle is safe [10, 14, 15] and convenient and can enhance muscular endurance [15]. Despite the similarity as walking, cycling has a superior range of motion (RoM) when compared to walking. Therefore, pedalling (during cycling) can help improve the functional range of motion of the lower limbs required in walking [16]. Cycling ensures that the trajectory of the feet can be restricted to a circle during performance and that the intensity of exercise can be altered by adjusting a few parameters on the cycling device without changing the course of the exercise [11]. As long as the training capacity of the patient can be adjusted to match their health status, physiologic response and rehabilitation evolution, cycling devices can perform a continuous and prolonged operation [17]. One unique feature of cycling is that it enhances exercise and training in persons who have one weak limb. In this case, the healthy limb helps the affected one through coupling of the pedals during the performance of the exercise. This encourages the use of the affected leg and the muscle control of the limbs, which may enable the affected leg to support more weight while standing [18]. The arm ergometer is also based on the principles used in cycle ergometry [10].

The main aim of the present study is to produce a dual-nature exercise bicycle that permits the exercise of both the upper limbs and the lower limbs either independently or simultaneously. The design technically combines both the leg ergometer and the arm ergometer in one device. For physically fit persons, it will permit the training of both the lower and the upper limbs. It is also applicable in the rehabilitation of patients recovering from conditions such as stroke.

2. MATERIALS AND METHOD

2.1 Materials for Design and Construction

The major materials used for the construction of the exercise bicycle include:

1. Rectangular hollow iron (thickness 0.2 cm)
2. Cylindrical iron pipe (\varnothing 4.7 cm, thickness 0.1 cm)
3. Flywheel (\varnothing 25.5 cm)
4. Pedals

5. Chain drives
 6. Tension/ resistance cable
 7. Cushion materials for the seat and handle bars
- Others are bolts & nuts, pedal support, electrodes, coolant, grease, car paint, thinner and screws. Some instruments were also used especially in the test and evaluation processes. These include the metronome, a heart rate monitor, and an anthropometer.

2.2 Design and Fabrication

A flowchart of the manufacturing process for the exercise bicycle is shown in Figure 1. The steps are briefly discussed as follows:

1. Design: the device was designed using AutoCAD design suite as shown in Figure 2. A photograph of the constructed bike is shown in Figure 3.
2. Material Selection and acquisition: the device was made from cylindrical and rectangular metal pipes with diameters and thicknesses described above.
3. Material preparations: this involved cutting the metals into appropriate sizes for the different parts of the bike and drilling appropriate-sized holes especially for bolts and screws.
4. Welding: the welding method deployed for the project is the arc welding.
5. Attachment of accessories such as cable trigger, pedals, saddle, etc.
6. Finishing: the welded joints of the metal pieces were grinded using a grinding machine to a smooth finish and the whole piece was painted using a spray painting machine.
7. Testing/Evaluation: A functionality test as well as an ergonomic evaluation of the bike was carried out. The flowchart of the processes is presented in Figure 1.

2.3 Evaluation

The Bi-Modal Exercise Bike was evaluated for comfort, functionality and ergonomic suitability. The evaluation was performed in compliance with the guidelines by the health research ethics committee of the University of Lagos.

2.3.1 Testing the comfort of the exercise bike

The bike was carefully evaluated by ten (10) randomly selected subjects. The goal of the exercise was carefully explained to the sample subjects and an informed consent was obtained from each one. The subjects assessed the seat (saddle), the pedal, the frame, the handle bar and general ease of use and completed questionnaires accordingly. In each case, the participants were required to give their judgement of

each of the components of the bicycle as listed, and their responses are as presented in Table 1.

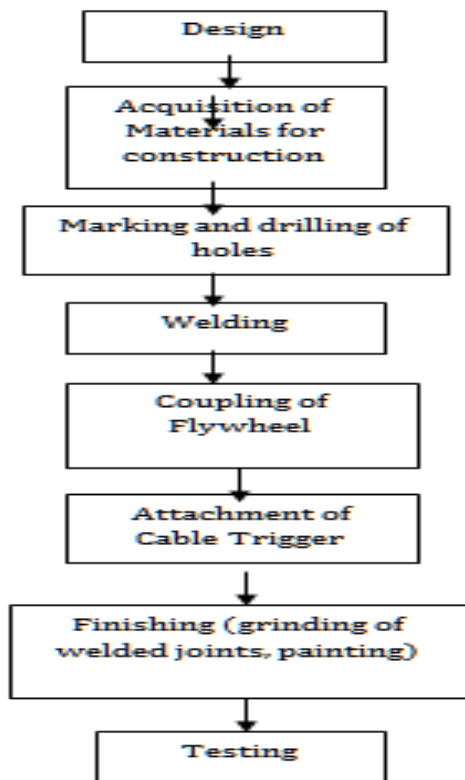


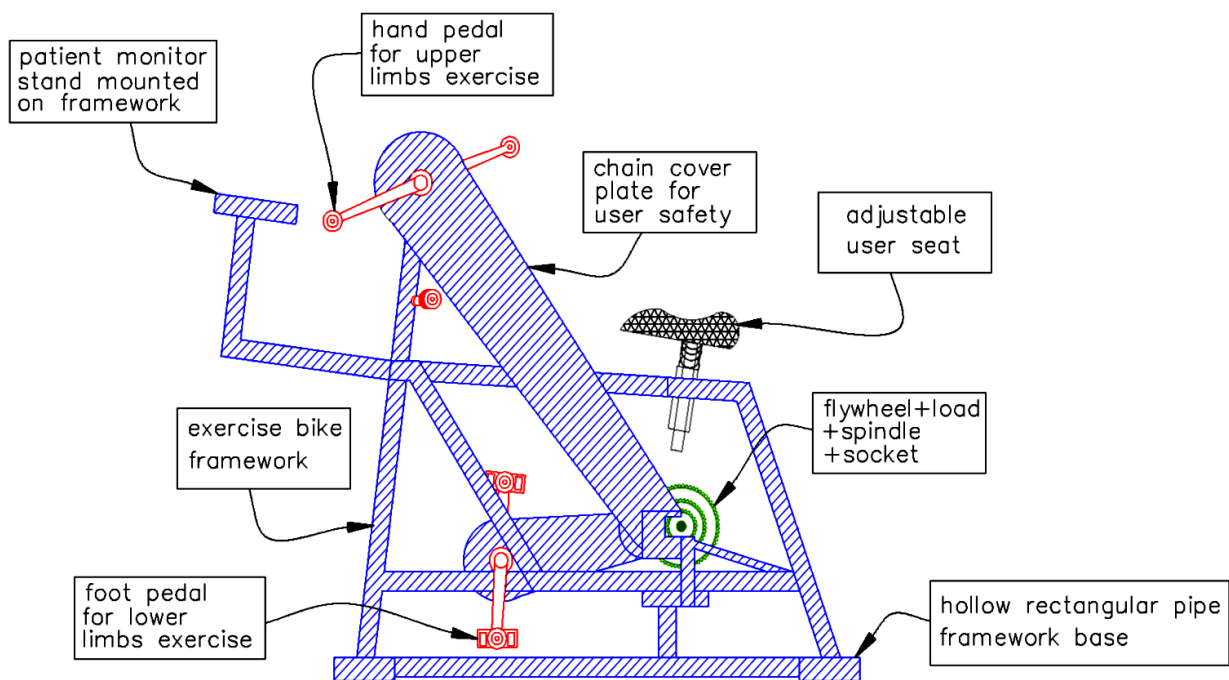
Figure 1: flowchart showing the construction processes for the bi-modal exercise bike

2.3.2 Testing with heart rates of subjects

According to the National Emergency Medicine Association, the heart rate is the number of times your heart beats per minute [19]. It may be obtained using a heart rate monitor or simply by placing the index and middle fingers together on the opposite wrist, about $\frac{1}{2}$ inch on the inside of the joint, in line with the index finger. The heart rates of the subjects were obtained before and after cycling on the exercise bicycle. The prototype testing of the bicycle ergometer was carried out using the following guidelines:

1. The heart rates of the participants were measured and recorded using a heart rate monitor.
2. Each participant was then required to perform some cycling on the exercise bicycle at a preferred load limit and to exhaustion.
3. The exercise was performed at 80 bpm (beats per minute). The rate of cycling was determined using a metronome.
4. The heart rates were again measured immediately after the cycling period and recorded.

The above procedure was performed with each of the study participants and repeated after two days.



DETAIL SHOWING THE BIMODAL EXERCISE BIKE

Figure 2: Side view of the bi-modal exercise bike design.



Figure 3: photograph of the side view of bi-modal exercise bike

2.3.3 Ergonomic evaluation of the bike

One hundred (65 males and 35 females) randomly selected persons, aged between 21-35 years, participated in the ergonomic evaluation. The anthropometric measures of the participants were taken (while they were in a sitting position) with the aid of an anthropometer. The knee height, popliteal height, buttock-popliteal length, buttock-knee height, thigh clearance, forward reach (sitting), and stature of the participants were determined. The anthropometric dimensions are as defined by ISO 7250 (1996) and reported in literature [20, 21]. The results are shown in Table 6.

3. RESULTS

Table 2 shows the heart rates of the test subjects before and after cycling. The means and standard deviations of subject's heart rate (HR) are presented in Tables 3 and 4.

3.1 Result of functionality test

A test-retest reliability method was adopted for the heart rate test and a correlation was calculated using the IBM Statistical Package for Social Sciences, SPSS,

version 21. A Pearson correlation coefficient was calculated for the relationship between the changed score of heart rate values of the first and second tests. A strong, positive correlation was found with correlation coefficient $r = 0.962$ at the level of significance $p < 0.001$, indicating a linear relationship between the two variables. The correlation result is shown in table 5.

3.2 Feedback from Users' assessment

The feedback from users who assessed the bike in an evaluation is shown in Table 1.

3.3 Ergonomic Evaluation

The result of the anthropometric measures of the study participants used for the ergonomic evaluation of the bike is shown in Table 6. To assess the ergonomic suitability of the bike, the knee height of the participants were compared with the seat-pedal height. Accordingly, the buttock-popliteal length as well as the thigh clearance was compared with the seat-handle post length and the forward reach (while sitting) was compared with the seat-handle bar length of the bike. The dimensions of the bike which were used for the ergonomic evaluation are shown in Table 7.

Table 1: Feedback from users of the bi-modal exercise bicycle

Subjects	Seat	Pedal	Frame	Handle Bar	Ease of Use
1	Very Good	Good	Comfortable	Comfortable	Comfortable
2	Very Good	Good	Comfortable	Excellent	Very Good
3	Very Good	Good	Very Good	Excellent	Very Good
4	Good	Good	Very Good	Excellent	Very Good
5	Very Good	Good	Very Good	Excellent	Comfortable
6	Good	Good	Very Good	Comfortable	Comfortable
7	Very Good	Good	Very Good	Excellent	Very Good
8	Very Good	Good	Very Good	Comfortable	Very Good
9	Very Good	Good	Comfortable	Comfortable	Very Good
10	Good	Good	Very Good	Excellent	Comfortable

Table 2: Results of heart rate measurements before and after cycling

Subjects	Heart rate before exercise	Heart rate after exercise	Deviation	Heart rate before exercise (2 days later)	Heart rate after exercise (2 days later)	Deviation
1	73	90	17	71	92	21
2	70	88	18	72	88	16
3	72	86	14	73	88	16
4	72	88	16	73	90	17
5	76	106	30	74	106	32
6	74	94	20	74	94	20
7	72	102	30	72	102	30
8	76	108	32	76	106	30
9	72	98	26	71	98	27
10	73	102	29	72	100	28

Table 3: Mean and SD of changed score values for the first and second heart rate tests (N= 10)

Variable	X±SD			
	Pre-test (Day 1)	Post-test (Day 1)	Pre-test (after 2 days)	Post-test (after 2 days)
Heart rate (beats/min)	73.00±1.89	96.20±8.08	72.70±1.57	96.40±6.98

Table 4: Mean and SD values for the first and second heart rate tests (N= 10)

Variable	Deviations		X±SD
	First-test	Second-test (After 2Days)	
Heart rate (beats/min)	23.20±6.86	23.70±6.34	

Table 5: Correlation between pre-test and post-test heart rate (HR), (N=10).

		First test	Second test
		First test	Pearson Correlation
	Sig. (2-tailed)		.000
	N	10	10
Second test	Pearson Correlation	.962	1
	Sig. (2-tailed)	.000	
	N	10	10

Correlation is significant at the 0.01 level (2-tailed); $P < 0.001$; $r = 0.962$

Table 6: Anthropometric measures of study participants

Anthropometric measure	Min	Max	Mean±SD	Standard error of mean	5 th percentile	50 th percentile	95 th percentile
Knee height	53.00	69.00	57.82±2.65	0.26	54.50	57.50	61.00
Popliteal height	37.00	55.00	45.30±2.88	0.29	41.00	45.00	49.00
Buttock-popliteal length	41.50	59.00	49.16±3.32	0.33	44.03	48.50	54.45
Buttock-knee length	49.50	67.00	57.16±3.32	0.33	52.03	56.50	64.00
Thigh clearance	9.50	18.00	13.30±1.90	0.19	10.00	14.00	15.18
Forward reach (sitting)	68.00	97.00	76.89±6.12	0.61	68.05	75.00	86.00
Knee height + thigh clearance	64.00	81.00	71.12±3.47	0.35	66.50	70.50	76.00
Stature	165.00	175.00	174.77±6.28	0.63	165.00	175.00	182.00

All dimensions are in centimetres (cm).

Table 7: Bike dimensions for ergonomic evaluation

Bicycle dimensions required for ergonomic evaluation	Seat-pedal height	Seat-handle post length	Seat-handle bar length
	Min = 54.5 cm	70.0 cm	70.0 cm
	Max = 80.0 cm		

The bike was designed for an adjustable range of knee height; therefore, the seat-pedal height is a range between 54.5 cm and 80.0 cm. This is to accommodate users of different heights and thus, different knee heights.

3.3.1 Knee height and seat-pedal height

The mean height of all the participants in the study is 57.82 cm as shown in Table 6. This value is well between the minimum and maximum values of the seat-pedal height. However, when a one-by-one comparison of the knee heights of all participants in the study was performed, the result is a 98% ergonomic suitability; with only two of the participants slightly falling outside of the range. Their knee heights were 54.3 cm and 54 cm.

3.3.2 Buttock-knee length and seat-handle post length

This evaluation is necessary to ensure that the user can comfortably use the bike without the risk of sustaining and injury resulting from hitting their knee against the handle post/handle bar. The buttock-knee length is better suited for this purpose than the buttock-popliteal depth which is often used to establish the suitability of a seat. The mean buttock-knee length of the study population is 57.1 cm. All one hundred participants in the study have their buttock-knee length less than the seat-handle post length, giving a 100% ergonomic suitability.

3.3.3 Forward reach (sitting) and seat-handlebar length

The forward reach (sitting) was used to evaluate the suitability of the handle bar length from a user's sitting position on the bike as well as the suitability of the arm pedals. The seat-handlebar and seat-arm pedal length was measured as 70 cm. The mean forward reach (sitting) of the study participants was found to be 76.89 cm. This value is approximately 7.0 cm higher than the seat-handlebar and seat-arm pedal length. A user is therefore required to bend the trunk slightly forward to attain a correct biking posture for improving the optimization between force and endurance in pedalling [22].

4. DISCUSSIONS

The seat (saddle) was designed for an adjustable range of users' heights. From the questionnaires completed

by the test users, all testers considered the seat either good or very good. The pedals were also positioned at an adjustable distance from the seat to suit users of different heights. The handle bars have cushion attached to them to prevent any kind of abrasion to the hands of the user during cycling. In general, all testers considered the exercise bicycle comfortable or very good with respect to the ease of use. The results of the performance and ergonomic evaluation carried out on the bicycle ergometer shows that the design is both reliable and valid and can therefore be recommended for use for fitness training and for rehabilitation.

5. CONCLUSION

The design and fabrication of a simple bicycle ergometer using locally available materials shows that some medical equipment can be locally manufactured and/or assembled. This realization thus has professional advantage for the Biomedical Engineers and economic benefit to Nigeria. The essence of the study which is to make available a bi-modal exercise bicycle was also accomplished. It is believed that the full commercialization of this idea will reduce the cost of buying separately, an arm and a leg ergometer, as both devices have been incorporated into one. In addition, people who may be recovering from stroke can use the device for rehabilitation irrespective of which limbs may be affected.

6. CONFLICT OF INTEREST

No conflict of interest exists among the authors (and/or with any organisation) with respect to this exercise bike and the publication of this article.

7. FUNDING

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