



MRI-Compatible Cardiac Exercise Device



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Client: Professor Naomi Chesler, Department of Biomedical Engineering

Advisor: Professor John Webster, Department of Biomedical Engineering

Abstract

In order to better understand the effects of exercise on patients with pulmonary hypertension, Professor Naomi Chesler would like to use MRI to accurately measure changes in pulmonary blood pressure and flow during exercise. Currently, there is no device on the market that allows a patient to exercise during a cardiac MRI scan. This device utilizes a stepping motion with adjustable weight resistance, and allows for the patient to exercise inside the MRI bore. The device was tested in our model MRI bore by four different subjects, and successfully raised their heart rates from initial values of 60-65 beats per minute (bpm) to 130, 128, 118, and 146 bpm respectively. Subjects with a range in height from 5'7" to 6'3" effectively tested the exercise device in an actual MRI machine. These results demonstrate that this design is able to raise the heart rate of fit individuals and can accommodate patients with a wide range of heights. In the future this design could be improved by increasing its durability and decreasing its overall size, however this initial design was a success and shows promise to develop into a marketable product.

Problem Statement

Design an exercise device to be used in cardiac MRI scans in order to diagnose and assess pulmonary hypertension.

Background

Pulmonary Hypertension:

- Abnormally high blood pressure in pulmonary arteries
- Decreased artery diameter
- Enlarged right ventricle
- Chronic decreased blood oxygen concentration

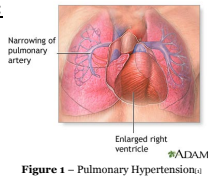


Figure 1 - Pulmonary Hypertension⁽¹⁾

Competition:

- Lode BV MRI Ergometer⁽²⁾
 - (>\$28,000)
- MRI-Compatible Treadmill⁽³⁾
- Previous UW BME Design Teams⁽⁴⁾⁽⁵⁾

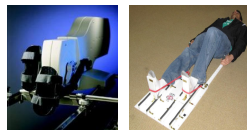


Figure 2 - Lode BV⁽²⁾ (left) and Spring'io BME Design⁽⁵⁾ (right) competitive devices

Design Requirements

- MRI compatible material
- Exercise within the bore
- Comfortable supine exercise motion
- Without risk for patient injury
- Minimal upper body movement
- Adjustable workloads
- Reasonable size and weight
 - 42cm to the top of the bore
 - 150 kg (patient + device)
- Sufficient resistance to increase cardiac output
 - Target heart rate is ~70-80% of maximum heart rate (220 beats/min - age)

Final Design

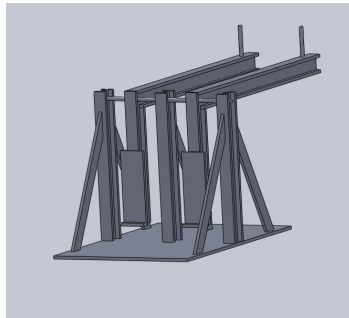


Figure 3 - SolidWorks model of the final design

Materials List

- 18 ft² (1.672 m²) of 1/2 in. (0.0127 m.) thick HDPE
- >100 solid brass screws
- 8 brass L brackets
- 3 ft. (0.914 m.) solid aluminum rod
- 20 brass nuts
- 2 acetel/glass ball bearings
- 2 rubber stoppers
- Yoga mat
- 2.25 in. (0.0572 m.) diameter PVC pipe
- Foam padding
- 2 nylon straps
- 2 tensioning buckles

MRI Testing

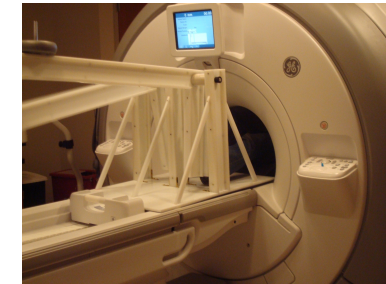


Figure 7 - Testing of the device in a MRI bore

- Tested at WIMR MRI lab
- Compatible with scanning coils & sliding MRI couch
- Subject heights varied from 5'7" to 6'3"

Exercise Testing and Results

Testing Setup:

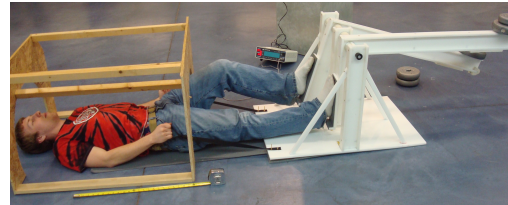


Figure 4 - The setup for exercise testing with the exercise device, mock MRI bore, and pulse oximeter

Determining Power Produced:

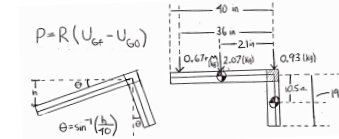


Figure 5 - Dimensions and mass / force diagrams for this device

- $P = 0.0561mR + 0.1023R$
- m is added mass (kg)
- R is the exercise cadence (steps/min)

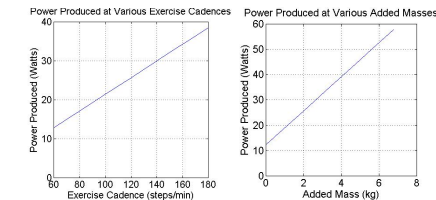


Figure 6 - Graphs of power produced for varied exercise cadences with constant $m = 2$ kg (left) and varied added masses with constant $R = 120$ steps/min (right)

	Power Produced for Various Combinations of Mass and Cadence (Watts)																											
	Exercise Cadence (steps/minute)																											
	60	70	80	90	100	110	120	130	140	150	160	170	180	60	70	80	90	100	110	120	130	140	150	160	170	180		
A	0.00	6.14	7.16	8.19	9.21	10.23	11.25	12.28	13.30	14.32	15.35	16.37	17.39	18.42	1.14	9.97	11.64	13.30	14.96	16.62	18.29	19.95	21.61	23.27	24.93	26.60	28.26	29.92
d	2.00	12.87	15.01	17.16	19.30	21.45	23.59	25.73	27.88	30.02	32.17	34.31	36.46	38.60	2.00	12.87	15.01	17.16	19.30	21.45	23.59	25.73	27.88	30.02	32.17	34.31	36.46	38.60
e	3.14	16.70	19.49	22.27	25.05	27.84	30.62	33.40	36.19	38.97	41.75	44.54	47.32	50.11	3.14	16.70	19.49	22.27	25.05	27.84	30.62	33.40	36.19	38.97	41.75	44.54	47.32	50.11
a	3.64	18.38	21.45	24.51	27.58	30.64	33.70	36.77	39.83	42.90	45.96	49.02	52.09	55.15	3.64	18.38	21.45	24.51	27.58	30.64	33.70	36.77	39.83	42.90	45.96	49.02	52.09	55.15
s	4.77	22.19	25.88	29.58	33.28	36.98	40.67	44.37	48.07	51.77	55.46	59.16	62.86	66.56	4.77	22.19	25.88	29.58	33.28	36.98	40.67	44.37	48.07	51.77	55.46	59.16	62.86	66.56
(kg)	5.64	25.11	29.30	33.48	37.67	41.85	46.04	50.22	54.41	58.59	62.78	66.97	71.15	75.34	5.64	25.11	29.30	33.48	37.67	41.85	46.04	50.22	54.41	58.59	62.78	66.97	71.15	75.34
	6.77	28.91	33.73	38.55	43.37	48.19	53.01	57.83	62.65	67.46	72.28	77.10	81.92	86.74	6.77	28.91	33.73	38.55	43.37	48.19	53.01	57.83	62.65	67.46	72.28	77.10	81.92	86.74

Table 1 - Power produced for many combinations of exercise cadence and adding mass

Maximum Exercising Heart Rates:

- Subjects used 6.77 kg additional mass
- Subjects worked at a cadence of ~130 steps/min
- Equivalent to ~62 Watts
- Tests lasted 10 minutes
 - Maximum heart rate during this time was measured via pulse oximeter

Future Work

- Improve durability
 - Remove bearings
 - Prevent lateral bar movement
- Decrease size
 - Shorter weight arms
- Increase range of motion
 - Move pedals closer to base
- Increase resistance capacity
- Better hand grips
- Synchronized alternating arm movement
- Get IRB approval for human testing
- Perform MRI scans while using the device to help research pulmonary hypertension

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Subject	Resting HR (bpm)	Exercising HR (bpm)	% Max. HR
1	65	130	65.33
2	62	128	64.32
3	62	118	59.30
4	58	146	73.37
Average	61.75	130.50	65.58

Table 2 - Resting, exercising, and % of maximum heart rates and averages for four subjects