MRI Exercise Device

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Abstract

Old age, obesity, and other disease states can cause a person to experience loss of breath, loss of consciousness, and even a stroke during seemingly normal activity. In order to analyze what is causing these events, it is important to assess the cerebral blood flow in subjects during exercise. Currently, the best available technology for assessing cerebral blood flow is magnetic resonance imaging (MRI). Implementing a device that allows researchers to observe cerebral blood flow on a subject during constant, dynamic exercise would allow them to assess the problems that may occur in elderly patients, and those with disease states such as obesity. The primary consideration for making such a device is its MRI compatibility. Specifically, the device cannot contain ferrous materials, it must fit on an MRI bed, and it must minimize upper body movement because the subject must be still to acquire an accurate image. The device also must allow the test subject to maintain constant exercise, while achieving a constant elevated heart rate. Through research and evaluation of the design ideas, a lever device that creates a constant resistance to vertical motion in the legs was chosen to provide an exercise mechanism, with straps on the subject's upper body to maintain stabilization. Testing was conducted to ensure the prototype's ability to provide a means of constant exercise for the test subjects. These tests yielded an average heart rate of 115 bpm, which was nearly compliant with the client's requirements. If given more time to work on this project, we are sure that we could create a prototype that is 100% compliant with our client's requirements.

Problem Statement

Motivation

This Project is designed to develop a device to allow researchers to observe blood vessel diameter, along with middle cerebral arterial velocity, of a patient during steady-state exercise. In order to observe these conditions, Magnetic Resonance Imaging (MRI) must be used, which limits the materials and mechanics of the device. In particular, we plan to construct a device that allows a patient to maintain upper body stabilization during continuous exercise while inside the MRI machine. The motivation behind this is that many elderly, obese, and diseased people are prone to loss of consciousness and stroke during activities such as walking up stairs, and other forms of mild exercise. By observing the cerebral blood flow during a period of increased heart rate, it could be possible to pinpoint some direct causes of fatalities and injuries in patients with these attributes.

Previous and Current Designs:

There have been two BME Design projects dedicated to making an exercise device for use in an MRI. The first design used a cycle motion to create the necessary resistance for elevating heart rate. This design was discontinued because the range of motion for the legs while in the MRI tube was too restricted. The second design used a stepping motion to create resistance. This design did not create enough constant resistance for the patient to sustain dynamic exercise. The Lode BV MRI Ergometer (**Fig. 1**) is a commercial MRI exercise device that uses a cyclic motion to create constant resistance. This design is effective, but costs around $50,000, which is out of our client's price range.

Figure 1: Lode BV Ergometer [1]

Figure 2: MRI Device [2]

Client Requirements

Primary Objectives

- Prototype must be MRI compatible
- Upper body movement must be limited
- Adequately raise heart rate to 120-130 bpm
- Accommodate varying body sizes
- Withstand frequent use for minimum of 3 years

Secondary Objectives

- Aesthetically pleasing
- Comfort for patients
- Easy transportation
- Work output measurements

References

1. Lode BV Ergometer. (2010). Lode Engineering, Retrieved from http://www.lode.nl/en/products/mri_ergometer.
2. MRI Machine, (2010). L & S, Retrieved from http://www.lawyersandsettlements.com/blog/tag/mri-health-risks

Alternative Designs

Cycle

Uses a cyclic motion to create resistance for exercise. Force is applied in the vertical (head-to-toe) direction, making stabilization difficult.

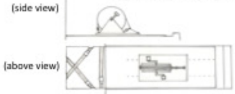

Figure 3: Cycle Design Sketch

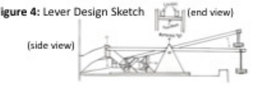

Figure 4: Lever Design Sketch

Lever

Levers attached at the knee region use a counter-weight to create a resistance to vertical motion.

Ferrous Boots

Harness the magnetic field of the MRI machine to create resistance to leg extension.

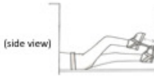

Figure 5: Ferrous Boots Design Sketch

Criteria		Possible Designs		
Considerations	Weight	Lever	Cycle	Ferrous Boots
Constant Resistance	20	18	18	20
Ease of Fabrication	10	8	9	10
Adjustability	10	9	6	10
Range of Motion	20	16	13	18
MRI Compatibility/Safety	20	17	15	2
Upper-Body Stabilization	20	17	15	13
Total	100	85	76	73

Table 1: Design Matrix for possible final prototypes.

Final Design

Conceptual Operation

Our final design uses the lever mechanism to create a vertical resistance in the knee region. The levers, fulcrum, and pivots are made of non-ferrous aluminum. Wood was used to make the backboard, fulcrum support, and foot pedals. The components are secured via non-ferrous brass screws. The vertical force orientation and waist strap are designed to minimize the upper body movement in the head-to-toe direction, thus improving the resolution of the MRI image.

Additional Design Features

① Swinging lever supports allow the lever to pivot on the fulcrum, compensating for extension of the knee.
② Foot pedals increase stability, and allow for a more natural feeling of exercise.
③ Padded mat adds comfort and back support.

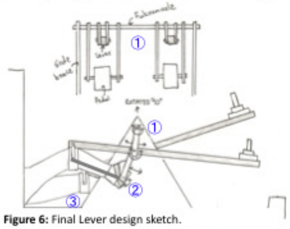

Figure 6: Final Lever design sketch.

Figure 7: Top view of Final Lever prototype support system.

Figure 8: Side view of the final Lever prototype.

Fabrication and Testing

Fabrication and testing of the prototype were almost simultaneous, as it was necessary to ensure the design elements functioned properly before further assembly of the device. In order to test the lever mechanism, we constructed a rough aluminum fulcrum and wood lever system. Each member of the team was strapped into the device and we tested to see if the mechanism could successfully elevate their heart rate. These tests yielded favorable results, with the subject reaching a heart rate of 117 bpm after 2.5 minutes of exercise.

Figure 9: Fabrication of support system

We confirmed that the lever mechanism was able to adequately raise each subject's heart rate; however, the device was unstable, and the upper body movement was substantial. In order to remedy this issue, we implemented foot pedals into the design, which guided the leg in a more controlled motion. After establishing the proper height of the fulcrum, as well as the lengths of the levers, supports, and foot pedals, we began fabrication of our final prototype.

In order to fabricate the backboard and fulcrum supports, plywood and wooden boards were cut to size. We secured each wooden component using brass screws (**Fig. 9**), and drilled holes for the fulcrum bar. Aluminum rods were used for the fulcrum, as well as pivots for the levers and foot pedals. For the levers, aluminum tubes were secured to the pivots and knee pads, with aluminum rods on the ends to hold the weights, which are made of plastic-encased concrete.

The wooden parts were painted, the backboard was attached, and the aluminum components were polished. The final prototype was tested in a similar fashion as the rough mock-up, and yielded much better results (**Fig. 10**). Because the fulcrum and levers were more secure, and the foot pedals guided the motion, the heart rate was more easily increased, and the upper body motion was significantly decreased. In the three tests conducted, the subject reached a heart rate above 110 bpm within 2 minutes of exercise, and the elevated heart rate stayed between 110-120 bpm for the remainder of the 10-minute test. The work and power output of the subject during exercise in the device was calculated, in order to visualize the work the subject was doing (**Table 2**).

Figure 10: Testing final prototype.

Pumps/min	Work/min (J)	Power/min (mW)
30	.44	7.3
45	.99	16.5
60	1.76	29.33
75	2.75	45.8
90	3.96	66

Table 2: Work and power output for varying exercise rates.

Future Work

If given more time to work on this project, we would first eliminate the ferrous bolts and replace them with aluminum or brass components. After removal of the ferrous elements, our prototype would be safe to use in an MRI machine, where we would test it for functionality. Ideally, test subjects of varying heights, weights, and ages would be able to test the device in the presence of our group and our client, in order to work out any kinks in the design. Depending on how the tests go, we would do our best to make sure that the patients are able to conduct dynamic exercise during an MRI scan, while maintaining upper body stabilization, and overall comfort.

Cost Analysis

Elements in final design
Aluminum Levers
1 4'x8' sheet of plywood
4 8' wooden boards
5 Aluminum Rods
Screws
Nuts and Bolts
Knee Pads
Strapping Materials
Mat for Backboard
Paint and Glue

We were given a maximum budget of $1000 for our prototype, and we were well below that mark. The most expensive elements of the design were the aluminum levers, which accounted for approximately half of the total cost of the device. Overall, with the design constraints we were given and the necessary materials needed to make our prototype, we were satisfied with the total cost.

Total Cost of Production: $ 275.50

Acknowledgements

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