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Equipment Testing and Evaluation

AN EXERCISE BIKE ERGOMETER DESIGNED FOR GENERAL ACCESSIBILITY

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ABSTRACT

Pope R, Millin J, Mehta A, Swift J. An Exercise Bike Ergometer Designed For General Accessibility. ***JEP****online* 2005;8(6):1-9. An Accessible Exercise Bike Ergometer usable by persons of various ailments as well as those without was built. The project began with a commercially available exercise bike (NordicTrack SL710) [1] to which modifications were completed to increase access to and usability of the bike to a diverse number of populations. The modifications included; seat assist, power adjustable seat, arm motion exercise, walk-through frame, lighted pedals, and improved user interface. The seat assist provides mechanical support to individuals who can no longer mount a bike unassisted due to insufficient upper or lower body strength. The power seat allows easy seat adjustment as well as allows unlimited positioning of the seat for users. The arm motion exercise allows a more full body workout than a pedal bike alone would provide. The walk-through frame allows unobstructed access to the seat. The lighted pedals allow them to be easily seen by users of low vision and help initiate motion for users with Parkinson's disease. The improved user interface addresses low vision and colorblind users. A prototype was built and tested using human subjects, and according to a survey completed by the subjects after testing asking them to rate their experience using a 1-10 scale, no significant difference in the accessibility was recorded between control and test subjects, demonstrating general accessibility. An increase in accessibility verses standard exercise equipment was observed for the test subject group, demonstrating an improvement for patients with ailments.

Key Words: Disability, Bicycle

INTRODUCTION

The aim of this project was to build a creative cycle ergometer that is usable by individuals with a diversity of abilities. The specific disabilities addressed included; post-stroke effects of limited arm function and necessity of a cane for walking, diabetes, poor eyesight, morbid obesity (BMI over 40), heart failure, generalized low strength and flexibility, and Parkinson's disease. Individuals that fall into one or more of these groups commonly complain of an inability to use standard exercise equipment, which leads to a higher proportion of these individuals living sedentary and potentially unhealthy lifestyles (2-5).

METHODS

To accommodate for the post-stroke symptoms of limited arm function, the ergometer arm exercise motion was made to be independent between the left and right side to allow just one arm to exercise. Additionally the push and pull resistances were made to be independently adjustable to accommodate for strength variations between the extensor and flexor muscle groups. To address the requirement of using a cane to walk, the ergometer was made to have an easily accessible cane holder to allow placement of the cane prior sitting. This cane holder was strategically placed to be intuitive for a cane user and so that the cane is within easy grasp when ready to exit the ergometer. For users with poor eyesight and those who are blind, the user interface was made with a large LCD touch screen and well-defined readouts and buttons.

Obese users require a structurally stable ergometer that is capable of supporting a load in excess of 180 kg (400 lb), so mild steel was used throughout for the weight bearing structures. To accommodate heart failure users, the ergometer contains an EKG readout, which could be coupled to a warning system against potential over exertion based on heart rate and/or arrhythmias (5). To assist users of low strength and flexibility, the seat position and all resistance controllers are readily accessible and require minimal effort to adjust. For users with Parkinson's disease, a method of helping initiate the movement to place their feet on the foot pedals was incorporated, as well as a method that will assist these individuals in entering information into the user interface (2,3).

NordicTrack SL710

The existing commercial design that was utilized for this project was the NordicTrack SL710. It was chosen because it is a recumbent cycle that incorporated magnetic resistance, EKG/pulse sensors, a console and ergonomic pedal placement (1).

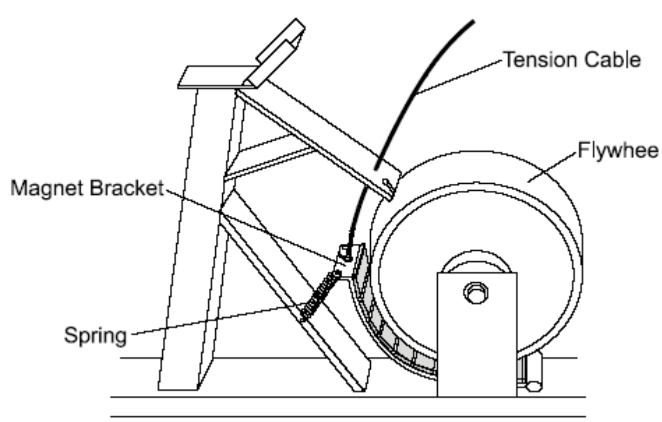

Figure 1. Sketch of Flywheel/Magnetic Resistance System (1).

A recumbent ergometer was chosen over an upright cycle ergometer due to two main factors: support of the user and stability. A recumbent style exercise cycle allows for the user to have their body supported when seating in a reclined seat compared to a bicycle seat that is used for upright stationary cycles. This reduces the amount of pain that is experienced by people in their lower back. Additionally, a user in a seated position is more stable than a user perched on a raised seat (6).

The magnetic resistance used on this style of NordicTrack cycle is referred to as SMR™, Silent Magnetic Resistance. The SMR system (Figure 1) enables changes in the pedaling resistance by having a metallic flywheel rotating through a magnetic field. As the flywheel passes through a greater portion of the magnetic field, the resistance is increased. The magnetic field is generated by permanent magnets that are mounted on a C-shaped bracket. Since the magnetic resistance is a smooth operating and easily controlled resistance design, it was kept intact and utilized along with the existing pedal drive train for rotating the flywheel.

Another aspect of the NordicTrack SL710 that was left basically unchanged was the CardioGrip™ EKG/pulse sensors. These sensors work by detecting the EKG through the metallic conducting palm sensors and then relaying the signal back to the computer where the heart rate can then be calculated and sent to the display. This pulse detecting system is not as accurate as other methods such as pulse oximetry or a telemetry strap, but it can be used by a wide variety of people with very low strength and dexterity and thus was appropriate for the prototype (1).

One final aspect of the commercial bike was deemed sufficient for a final prototype, the seat. The original seat padding and general shape was left intact and the angle between the seat base and seat back was left unchanged. The one small addition made to the seat base was the lift seat assist system, which is addressed elsewhere in this report.

Modifications to Existing Device

The first concern addressed when modifying the commercially available bike for general accessibility was the incorporation of a walkthrough access, or zero step-over technology (Figure 2). Zero step-over technology means that the user would not have to lift a leg and maintain balance on one foot to get onto the bike.

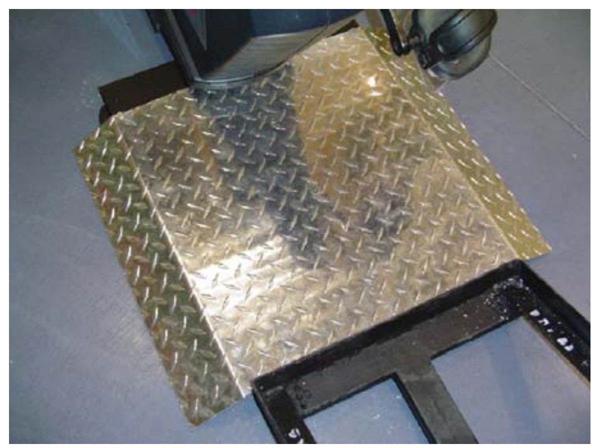

Figure 2: Zero step-over technology access walkway.

The implementation of a zero step-over technology led to one other major and beneficial change to the commercial bike. To make more room for the walkthrough, the original manual seat locating system was eliminated and replaced with a power seat system that was mounted lower than the original system.

Additions To Existing Device

Power And Lift Seat

The powered seat locating system was made in such a way that the seat would travel through the same path in space as the original system. Thus the angle of the seat track was maintained at approximately the original 22.6° and the seat was placed in exactly the same reference to the pedals as it was originally. A new mounting platform for the seat and the future arm motion was created utilizing rectangular steel tube. On the outside of the new seat platform, roller blade wheels were attached that would ride on a new track system. Additionally, secondary wheels were attached to the bottom of the seat platform and these wheels ride below the seat track to keep the seat platform locked to the track in the same way a roller coaster is locked to its track. The new track system was constructed from angle iron set to the width of the seat platform and the proper length to cover the full range of travel of the 227 kg (500 lb) linear actuator, which is used to control the seat motion.

Once the locating system for the seat was established, improvements for the seat itself could also be addressed. Since it can be difficult for some users to stand from a fully seated position due to insufficient upper or lower body strength, a lift assist based on a 45.4 kg (100 lb.) pressurized lift cylinder was incorporated into the seat (Figure 3).

As the seat travels up, a portion of the force that the lift cylinder can generate is exerted to aid the user in getting to a standing position. Additionally, a spring was added to the force cylinder so as the seat angle approached 0°, the force generated by the spring would add to the total force exerted and the piston force would not go to 0 kg. The lift force generated follows the graph seen in Figure 4. A limiting chain was added to allow the seat to achieve an angle no greater than 45° for ease of sitting down.

Arm Motion Exercise

Along with lower body workout provided by the cycling motion, users can also obtain an upper body workout using the arm motion exercise. Furthermore, both components (arm motion and the cycling motion) can be performed together to allow for a total body workout. Also, since the upper body and lower body workout are independent of each other, the user has total control of his/her exercise routine.

The arm motion is controlled by four independently variable resistance pistons. Using independent pistons is unique in the sense that it allows patients with limited one arm function to conduct exercise with only their functional arm and not worry about the unused handle coming back at them, as it would if the arms were tied to the same resistance system. The pistons are capable of a 1 to 91 kg (5-200 lb) load controlled with an adjustable dial that ranges from 1 to 12, with increasing numbers on the dial corresponding to higher resistances. The two pistons are attached to each handle to provide both push and pull resistance. A free body diagram for the piston placement is shown in Figure 5. It was found that the minimum force a user would be required to exert on the arm handle to move it is only 1.7 kg (3.7 lb), while the maximum force can be up to 42.2 kg (93.08 lb). The final design is shown in Figure 6.

Arm EKG Handles

Arm handles were incorporated to give a clean place to grip when exiting the device and as a convenient location for the EKG/pulse rate sensors (Figure 7).

Figure 3: Lift seat configuration.

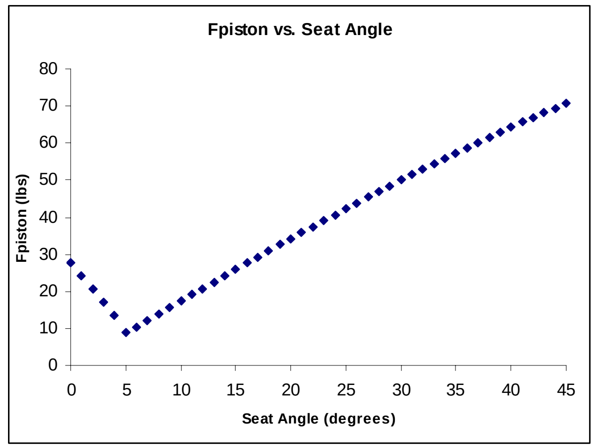

Figure 4: Lift force as a function of seat angle.

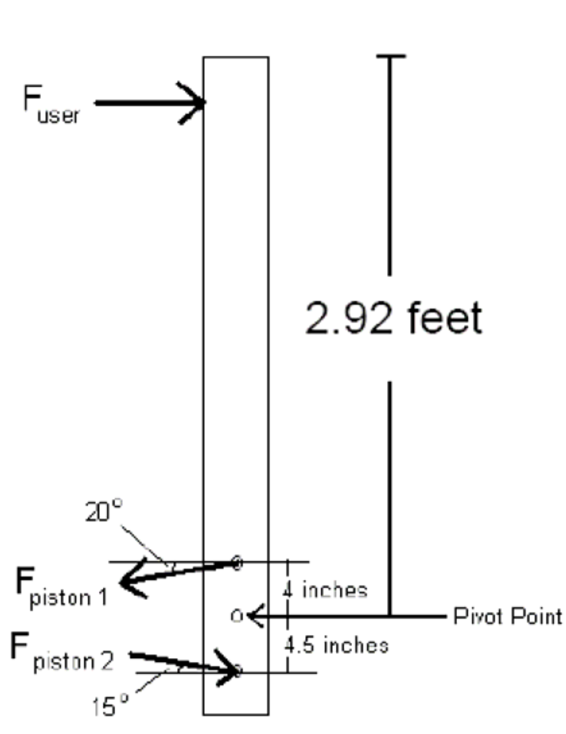

Figure 5: Free body diagram of arm motion. F_{user} is the force exerted by the user, and $F_{piston\ 1}$ and $F_{piston\ 2}$ is the force of the piston resisting the motion induced by the user.

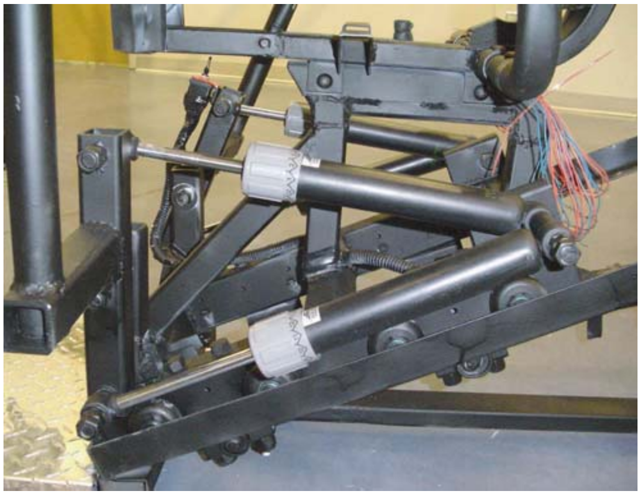

Figure 6: Arm motion exercise.

Figure 7: Raised arm handles with heart rate sensors.

The placement of the handles puts them within easier reach of the user than if they were by the user console and also eliminates potential motion artifact in the EKG signal that would come if they were placed on the arm motion handles.

The handles were mounted on a pivoting system to allow each handle to be pivoted out of the way of the user to allow uninhibited access to the seat. The pivot system consists of two bolts that pass through the handlebars. Each bolt rides in a notch that allows a $^1/_8$ rotation of the handle. When each of the $^1/_8$ rotations occur together, the handle can travel through a ¼ rotation and rotate up and out of the way of the user.

Wireless LED Pedals

Some people with Parkinson's Disease have an inability to initiate motion, which means that if you tell them to take a step they can not do so, but if you tell them to step over a line draw on the floor they are able to do so. To address this we theorized that by putting red LEDs into the pedals and coupling that with audio output instructing the user to place their feet on the pedals, this will help users with Parkinson's to overcome the problem of initiating motion (2,3).

Figure 8: Illuminated left pedal.

A second advantage of incorporating wireless LED pedals became apparent during testing; people with low vision are more able to see the pedals when the exercise bike is on a dark floor with the presence of the illuminated LEDs. Figure 8 shows the LED clearly illuminated on the pedal.

The LED system was made wireless to overcome the problem of the continuous rotation of the pedals and also to make it triggered automatically upon sitting on the seat.

User Interface

To increase the ease of viewing and the ease of use of the user interface, a completely new interface was made using a 15" touch screen monitor and LabVIEW™ programming (National Instruments, Austin, TX). The new user interface was made to contain large lettering, high contrasting images, large buttons/controls, easy to understand terminology, simple controls, and advanced layout / simple layout options to tailor to the user (6). A typical screen shot is seen in Figure 9.

Human Subjects Testing Procedure

Permission to perform human subjects testing was obtained through the UW Hospital Institutional Review Board. Subjects in the study were from the Madison, WI area, between the ages of 18-70, and recruited through advertisements placed on campus billboards. The subjects were required to sign an approved consent form before beginning the study. The test group consisted of four control subjects of normal abilities and four test subjects possessing some of the targeted disabilities. Test subject one was obese, test subject two had diabetes and generalized low strength and flexibility, test subject three had poor eyesight and heart failure, and test subject four was legally blind. Due to a design deadline, subjects with deafness, Parkinson's disease, and post-stroke symptoms could not be obtained. The subjects were asked to enter and exit the bike and performed an optional short exercise. Following this the subjects were asked to complete a short questionnaire ranking the accessibility and usability of the bike.

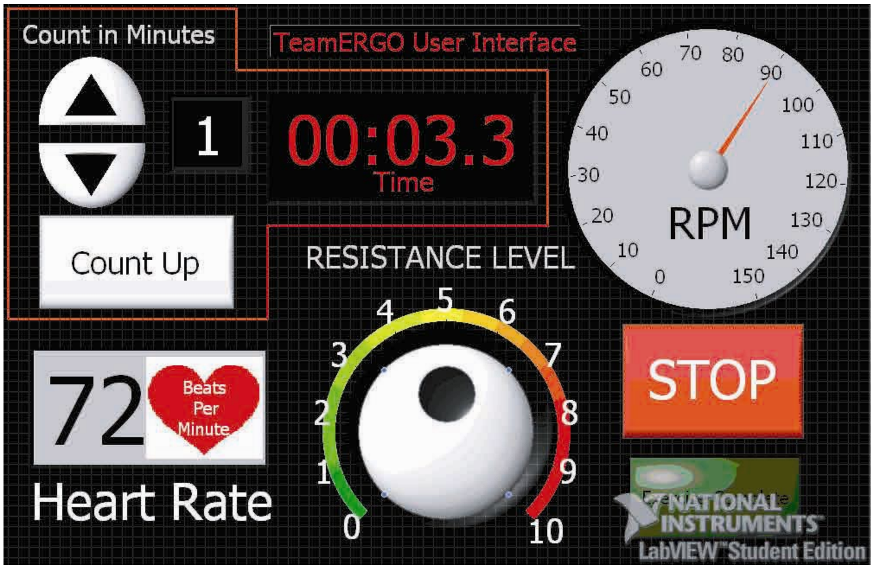

Figure 9: User interface Screen Shot.

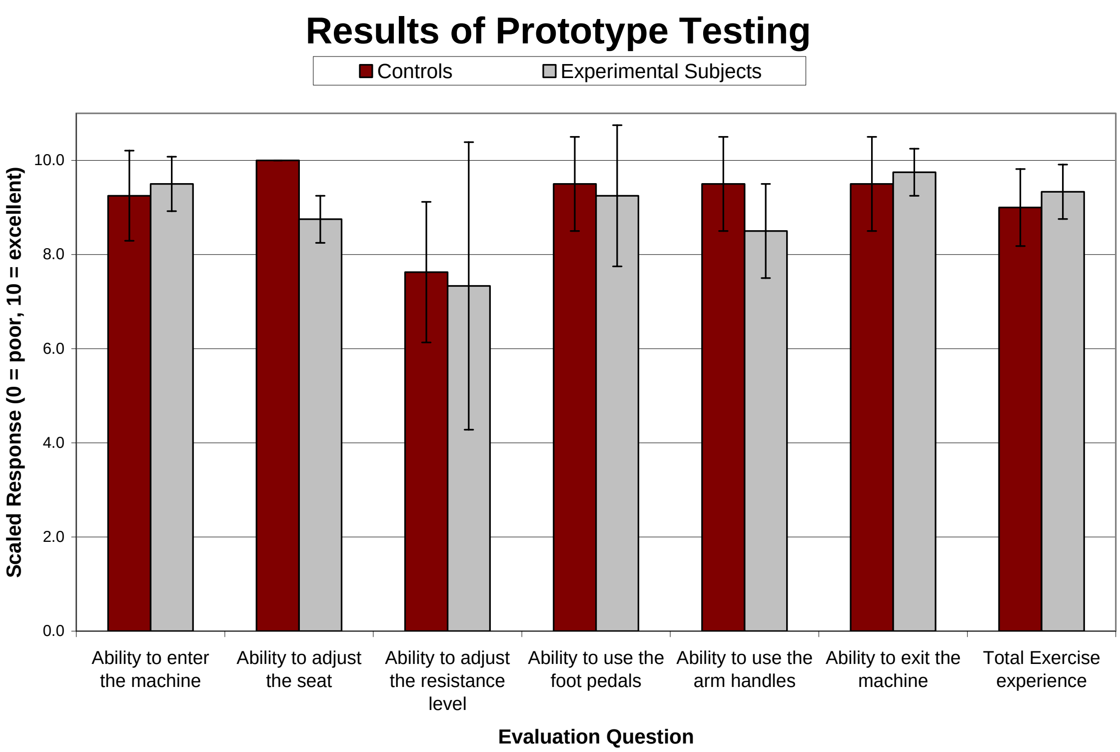

Figure 10: Results of human subjects testing with standard deviations.

RESULTS

Four experimental subjects and four control subjects were recruited. The responses obtained from each participant through the post-experimental survey are tabulated and reported below in Figure 10.

It was found that most participants found the prototype readily accessible. Because of the small number of participants in both the control and experimental group, the standard deviation was quite high. Based on the results of the ability to enter and exit the prototype, both groups found it easy to access the device and exit upon completion of exercise. Nearly all subjects liked the idea of implementing the seat assist because they liked the extra help when standing from a fully seated position. The lighted foot pedals was another feature brought up by our participants as positive. Since they were activated wirelessly upon sitting, it was very easy for the subjects to find the foot pedals, especially those with low vision. Lastly, most subjects liked the idea that we added an arm exercise to the bike. They felt that it gave them more variability in their exercise by allowing upper and lower body workouts. Our experimental groups pointed out that having a bike with dual independent upper and lower body exercises was unique in the exercise equipment field.

One of the main negative feedbacks that we received was that it was hard to adjust the pistons for the arm exercise. Because we had to change the initial design of the arm exercise to increase bi-directional function, the location of the pistons and number of pistons was changed, which made it harder for users to adjust the piston resistance. The design has 4 total pistons, two of which are close to the ground and thus farther from the seat.

In general, users appreciated the added components such as the seat assist, power seats, and the simplified user interface. Our test groups liked the newly designed bike we created and were able to see it being useful for people with various disabilities as well as those without.

DISCUSSION AND CONCLUSIONS

Most participants found the prototype readily accessible and were able to provide useful feedback for the design team. While subjects and controls in general rated the device high in quality, certain areas were found that require improvement. First, and most importantly, the user interface must be completed. To accommodate blind users, an audio output should be incorporated. This can be done using the LabVIEW program, and only requires additional computer programming and the downloading of the program onto the computer. Second, an additional handgrip should be added to the arm motion handles below the current grip to make the overall length of the grip four inches longer. This will allow a place to grab on the handles for shorter people instead of them holding onto the bare metal of the arm motion handles. Third, there is a section of the seat track that could potentially cause injury and should be changed. A section of the angle iron that was used to construct the track protrudes near the walk-through platform. When the seat is moved forward, this piece could possibly catch the front of a user's shoe, thereby compressing the user's foot between the steel and the seat platform. By cutting this small section out of the seat track, this problem can easily be eliminated without changing the function of the track. Fourth, the weight of the device is too heavy for users with disabilities to transport. A solution to this problem is to use a lighter, yet still sufficiently strong, material throughout.

With these improvements in mind, we feel that we have built an exercise device that would be enjoyed by people with various abilities and that our device would be of great benefit for people who may have trouble using currently existing exercise devices.

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APPENDIX

- Post Experimental Survey -

How do you rate the ability to enter the machine [on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

How do you rate the ability to adjust the seat to your liking on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

How do you rate the ability to adjust the resistance level of exercise to your liking on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

How do you rate the ability to use the foot pedals to perform lower body workout on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

How do you rate the ability to use the arm handles to perform upper body workout on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

How do you rate the ability to read the control screen on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

How do you rate your total exercise experience [on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

How do you rate the ability to exit the machine on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

Did you find the seat assist helpful [yes or no]? _______________

How do you rate your experience using our prototype today on a scale of 1-10, with 10 being the easiest and 1 being the hardest]? __________

How would you improve this device?

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Other comments or questions?

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