

A HOME DEVICE FOR VESTIBULAR STIMULATION

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EXECUTIVE SUMMARY

The goal of this project, which was presented to the team by Kevin Maher (President of Advanced Therapeutic devices), was to develop a product prototype for safe, vestibular stimulation for children with developmental disabilities. Vestibular stimulation is a form of therapy that increases muscle coordination. It works by stimulating the canals and sacs within the inner ear that detect accelerations. The project targeted children from ages two to seven years old, under 48 inches tall, and less than 100 lbs. The production device also sought to differ from stimulation devices found in hospitals in a few respects: it would cost under \$5000, reside in a patient's home, be hand-powered, and be controlled by an average person. The final device needed to support a 200 lb. load at the edge of the structure and adjust for the center of gravities for the range of children.

After sessions of brainstorming, the team produced three workable layouts, only one was adequate. The final setup had a structure of $\frac{1}{4}$ in. aluminum structural pipe similar to a football field goal. This structure mounted on a single bearing housing and steel shaft. The final design had two bars to mount weights in order to adjust the center of gravity. The prototype, however, used a swinging bar, lock, and a sliding weight. The final prototype had an adjustable footrest and a five-point restraint harness. The final cost and weight was \$1700 and no more than 500 lb. The design met all of the requirements and had adequate safety for any child's needs, but the team thought the design needed significant changes before it became a final product.

INTRODUCTION

This report discusses the results of research, design, and construction of a device for vestibular stimulation. The final results come from one quarter of design and one quarter of building the prototype.

The vestibular stimulation project began with Gregg Baker and Victoria Drake. The two senior design students received this vestibular stimulation project from Kevin Maher, President of Advanced Therapeutic Devices (ATD). He desired a cheap, safe, and reliable system for delivering vestibular stimulation, since children with developmental disabilities have generally shown improvements in areas such as muscle coordination after receiving this sort of treatment. This actual process of vestibular stimulation will be discussed in greater detail later in this report.

Kevin Maher wanted a human-powered, vestibular stimulation device different than others found in hospitals. These different motor-powered versions cost a large sum of money and cannot be easily installed in a person's home. Maher asked the team to design a more practical, human-powered version that costs less, resides in a person's home, and provides the same treatment. He imagined the prototype would serve as a starting point for a production product.

This prototype needed to meet these general requirements:

- Provide for the child's safety
- Have adequate comfort
- Cost under \$5000
- Have a fairly simple assembly
- Fit within a common home
- Ship in small, few, low-weight parts
- Require minimal effort to rotate
- Be easily controlled by an average person
- Adjust for a range of children's sizes
- Produce minimal noise and vibrations
- Rotate about both a vertical and horizontal axis

The chair aimed to accommodate children from ages two to seven years old, up to 100lbs., less than 48 inches tall, and the group assumed the par-

ents would rotate the chair for the children. In addition, Maher required that the prototype sustain a 200 lb. load at the farthest side of the structure. The group set the cost requirement at \$5000 since the motorized stimulation devices found in hospitals can cost more than five times that amount. The team also saw through research that the chair needed to rotate in a certain manner to provide adequate stimulation.

I joined the team to assist in the design, manufacturing, and research as part of the Honors Research Program. Patrick Wallis joined the group to provide manufacturing experience and more insight into the design of the vestibular stimulation device. The whole team worked together to design and construct the device that would stimulate a child's vestibular system.

The following sections of this report follow the basic process of design and testing. The background research into the vestibular system and its stimulation gives essential information on what the device will accomplish. From this research, the group developed many ideas, but decided on a single application. Next, the team finalized the design with estimations of the criteria (cost, forces and moments, weight, dimensions, comfort, and safety). The final structural layout went into prototype production, which went through a short phase of testing. After observing the model device at work, the group found that it satisfied all of the basic requirements, but thought it was too complicated a structure for a production model.

BACKGROUND OF THE VESTIBULAR SYSTEM

In order to gain a better understanding of the design requirements, the team gathered research about the vestibular stimulation process to understand how the vestibular system senses motion during both linear and angular acceleration. This went to help the device achieve the best results. The group learned that the vestibular system gives the sense of all accelerations in addition to the five senses of taste, touch, hearing, smell, and sight. This bodily system sits in the inner ear and has two parts, one for the sense for angular acceleration (or rotation) and another for the sense of linear acceleration.

The first set of organs, the three canals in the inner ear, detects angular acceleration (see Figure 1). The posterior, horizontal, and superior (or ante-

rior) canals belong in three planes oriented at right angles to each other. Thus, each channel approximately corresponds to the three axes of rotation: pitch, yaw, and roll (Coulter). These canals also contain a fluid called endolymph that circulates in these three approximately orthogonal channels (Vilis).

The endolymph moves cilia, which lie within a gel-like substance called the cupula (Coulter).

When the body or the head rotates, the endolymph within the canals begins to flow, which pushes the cupula. The cilia, in turn, send signals to the brain when they bend to the side. The brain then interprets these signals as a rotational sense, like the sense when you shake or nod your head. For longer, sustained rotations, the speed of the endolymph eventually catches up with the rotation of the body, and the cilia will not send a signal. This makes a person feel stationary even while it rotates. If the body suddenly stops from rotating in this state, the person feels dizzy because the endolymph rotates and the body does not. The brain actually receives a signal that the body is rotating when it is still in reality (Coulter). Spinning around the end of a baseball bat for a sustained period and walking afterwards is difficult for this reason. All this information tells us that the vestibular stimulation device should have the ability to change velocities quickly to prevent the patient from getting used to long, sustained rotation.

Two sacs, called the utricle and saccule, work in the vestibular system to produce linear acceleration senses, like the sense from falling or leaning. The human body has two sacs in order to provide sense in two planes of motion, one for the horizontal plane and one for the vertical plane (“Equilibrium and Perceptions”). The saccule senses vertical acceleration and the utricle detects horizontal acceleration (Coulter). These sacs also tell the brain the body’s

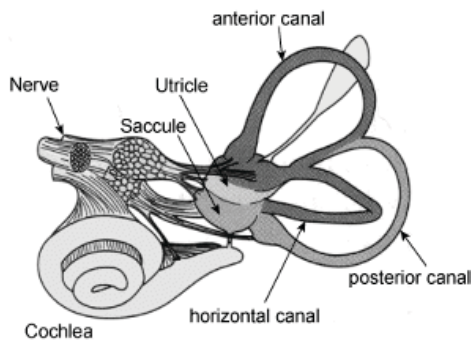


Figure 1. The three canals and the two sacs, the utricle and saccule, are shown here. Source: <<http://en.wikipedia.org/wiki/Image:VestibularSystem.gif>>

direction relative to gravity, or in other words, which way is up. The stimulation of each sac happens in a similar way to the semi-circular canals. When a gelatinous substance and ear stones in the sacs move nerves, the nerves become stimulated and send a signal to the brain (Vilis).

So what does this all do for the body? Basically, the vestibular system helps a person know about balance, motion, and body position (Coulter). The two components of the vestibular system help with motor coordination and stimulate muscles to keep posture (“Equilibrium and Perceptions”). Also, the two sets of canals in either ear work together to stimulate eye muscles so a person can focus even while the head rotates. This reflex is called vestibular ocular reflex, or VOR (“Equilibrium and Perceptions”).

The team’s vestibular stimulation device will excite the vestibular system and develop all of these vestibular functions. Some research has shown that this stimulation can help development of many different body functions, one of which is motor coordination. Some therapists have already implemented this sort of stimulation and observed somewhat positive results in some patients’ development (Ardent). Still, the patients needing these devices cannot afford motor-driven versions of their own and must make frequent trips to hospitals for treatment. The vestibular stimulation prototype the team designed can get the same results without the motor, with less cost, and also remain in a patient’s home.

A wide variety of people have shown vestibular dysfunction. An examiner could notice vestibular problems in people with dyslexia, “...schizophrenia, autism, psychosis, behavior disorders, Down’s Syndrome, minor neurological impairment, hyperactivity, communication disorders, adolescent idiopathic scoliosis, multiple sclerosis, cerebral vascular accidents, mental retardation, developmental delay, otitis media, and Parkinson’s disease” (Greg). The final vestibular stimulation prototype aims to help children with these kinds of disorders.

In “Vestibular Stimulation as a Form of Therapy,” Kelly Greg discussed the optimum configuration for a vestibular stimulation device that would help the people with the aforementioned disabilities. She noted a child needs rapid accelerations for high stimulation. If the stimulation system moves slowly and

repetitively, it could actually have an inhibitory effect. In addition, different directions of rotation excite different canals and the utricle and saccule experience the most stimulation when upside down. Greg also stated the patient must experience constant velocity rotation for at least one minute before coming to rest to achieve maximum stimulation. If a constant velocity lasts less than a minute, the fluid in the semi-circular canals return too quickly to the resting state. The team kept all these requirements in mind while completing the design of the prototype.

SUGGESTIONS OF DESIGN

The vestibular stimulation team came up with many ideas on methods of delivering the therapy. For some ideas, the group built upon the strengths of Kevin Maher's prototypes. In other cases, ideas broke away from conventional concepts in order to produce a sufficient solution. In the end, only a few concepts looked like real possibilities. The more practical concepts are shown in Figures 2-4.

Each idea had its own problems and advantages. Some, like the "concentric circle" design in Figure 2, would provide fast rotation, but had inherently dangerous characteristics. Also, some concepts would operate in a sort of unpredictable motion, which would pose a big problem for the controlled stimulation that the problem required. The team also noted the ideas that would have the most frictional losses and those with a good amount of comfort.

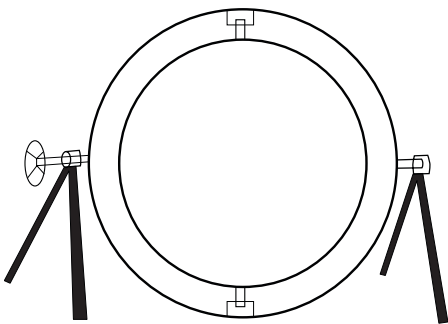


Figure 2. The first design concept has two concentric circles for two axes.

After discussions with Maher, the group chose the second idea (Figure 3), a vertically oriented chair that rotates about a horizontal axis on a rotating base. This application offered structural stability, simplicity, comfort, and good overall control of the motion.

METHODS OF DESIGN

The majority of the team's design work came from research on components, ideas on application of these components, and calculations. Since this device did not have any predecessors to follow, aside from Kevin Maher's small prototypes and experience, the group relied on innovation.

A few factors played major roles in detailing the idea. These held the focus of the group during the design:

- Friction within the base
- Variable center of gravity
- Structural loads and moments

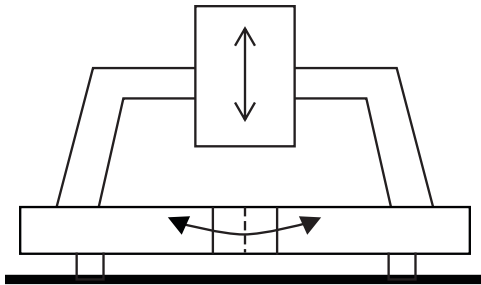


Figure 3. Concept two is more basic and simple than the other ideas.

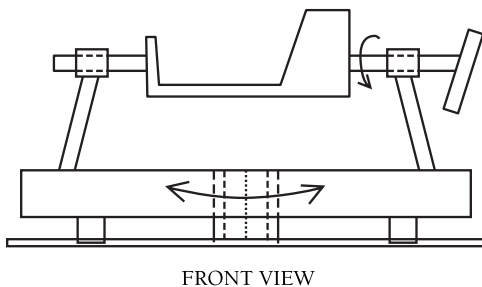


Figure 4. Concept three has possibilities, but would be uncomfortable.

400 ft-lb moment, and sustained a 75 lb. force 4 ft. above the base.

As research, ideas, and specifics developed, the team updated SolidWorks drawings in order to visualize the prototype's layout. Once the team built the prototype, it went through a series of tests. In addition, the prototype con-

For details, such as the size of piping, shaft diameter, and other specifications, Gregg Baker and Victoria Drake performed calculations in order to find more specific external load requirements. They found statistics on loads on the piping, pipe fittings, bearing housing, and base. These calculations helped the project meet its goals. For example, Baker found that the base (with the appropriate structural dimensions) supported a 200 lb. load at the edge of the structure, resisted falling over from the resulting

firmed the center of gravity calculations. Finally, loads at points of interest confirmed the soundness of the structure.

FINAL DESIGN

The final design, illustrated in the attached appendix, meets all of the requirements for a successful home vestibular device (please refer to the appendix to clarify the layout of the assemblies mentioned in this section). Some of the highlights of the structure include an adjustable restraint and footrest, an adjustable center of gravity, good safety, light components, and compact design.

The basic support structure follows a sort of field goal shape. This offered the best solution to the frictional problem. With rollers, a person driving the device would exert too much effort, but with a single, central housing, the device rotates freely. The base has 5 four-foot struts mounted to the bearing housing with half-inch bolts. The base also uses 1.5 inch diameter structural aluminum tubing for the support structure, which connects with aluminum pipe fittings pre-drilled for a set screw. The other side of the pipe fitting has drilled holes to lock together with the tubing by a bolt.

The seat needed adjustability, comfort, and rigidity. The chair itself has a plywood back and is supported by T-slot structural members. The plywood provides adequate support while T-slots allow an assembler to easily bracket the entire structure together. The chair has two angled slots with an adjustable shoulder height to accommodate children of different heights and shoulder widths. The restraint system is a five-point harness, which provides excellent safety. The fact that this harness can be found on a few children's car seats speaks to its security. This five-point harness tightens by a single belt that passes under the seat into a locking mechanism. This allows the seat to secure quickly and with minimal effort, which posed a concern earlier in the design.

The chair sides have 2 four-foot diameter plywood disks mounted on each side of the chair in order to keep the child's arms from moving outside the chair. They also help a caregiver propel the chair with minimal effort and without safety problems. The high-quality plywood disks have no dangerous gaps, rough edges, or open holes.

The bearing housing is the most critical piece in the design. It supports the 400 ft-lb moment for the two bearings held within it and it allows the entire structure to turn freely. This critical piece holds the bearings and the lathed shaft securely. The bearings themselves sit on the stepped shaft, which attaches to the pipe fitting at the center of the chair's support structure. The housing has a flange with 10 points of attachment for the base struts and this flange has a weld on one side to attach to the bearing housing. Destruction testing of the weld showed that it exceeded the strength requirements for the structure.

The most difficult task presented to the team was the adjustable center of gravity. To accommodate for all the different positions of the target child, the design specifies T-slots behind and below the chair that span the distance between the two disks. The team originally planned for a person to simply strap added weights to these bars in order to shift the center of gravity in line with the axis of rotation. However, this design characteristic changed after we constructed and tested the actual prototype.

PROTOTYPE CONSTRUCTION AND RESULTS

During the second quarter of this project, the group constructed a prototype to test the final design and to demonstrate that the actual product met the given requirements. The team encountered a few problems, but eventually ended up with a result similar to the original layout.

First, T-slots are relatively simple to put together, but they have a couple major problems. The T-slots ended up being the most expensive component on the structure. Furthermore, the advantage of using T-slots was also their biggest nuisance. T-slots do not require much cutting, welding, or drilling, but they need countless screws and nuts to hold them together. The complex framework posed a tedious task of assembly, even for the team—the actual designers. A user of this chair would have an even harder time trying to assemble it. The extensive T-slot chair frame may be just too convoluted and expensive to suit a production model.

However, the harness succeeded in providing good restraint. It secured some test weights well and even safely held one child during rotation about

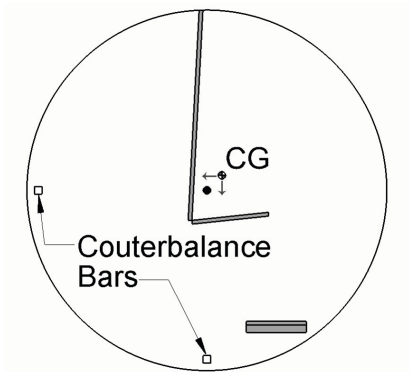


Figure 5. Two counterbalance bars sit opposite the center of gravity for extra weights to offset the center of rotation.

the horizontal axis. Also, the single tightening strap worked well enough to tighten the entire harness in one pull. The entire seatbelt system ended up taking slightly longer than expected to get in and out of, but it was still short enough and well worth its restraint capability.

Third, the bearing housing posed many difficulties. Of all the parts, it required the most manufacturing because it was the most critical part.

The process of making the housing consisted of numerous time-consuming tasks: cutting the base plate, cutting the housing, milling the inside of the housing, and drilling set screw holes. All these extra manufacturing processes increased the cost of the structure. The housing required a large amount of machining because the bearings would not stay in place while the chair rotated. The shaft and tubing structure actually wobbled within the bearing housing, and the bearing itself was slipping out of the sleeve. A set screw hole at the top of the bearing housing and a ridge on the bearing for a set screw to hold it solved the problem. In the end, though, the housing worked very well. The bearings would glide with little frictional loss and the stability issue became almost nonexistent.

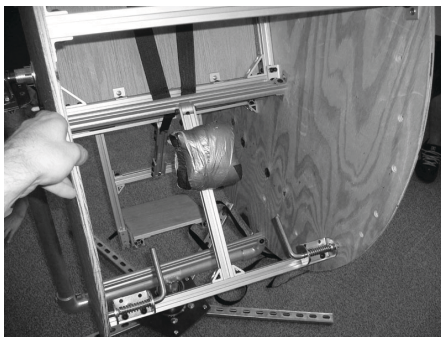


Figure 6. A swinging bar and sliding weight can lock in to different angles to offset the center of gravity.

While the bearing housing had major issues, the counterbalance tests gave us the greatest insight. The group tested a new idea. One bar could swing to different angles to offset the axis in different directions. Also, a weight mounted on the slider could sit at different distances to change the amount of offset

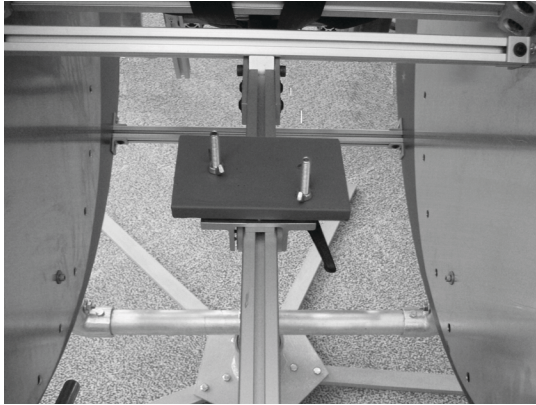


Figure 7. The final counterbalance idea uses mountable plates of 2.5 lbs. each

(see Figure 6). Holes in the disks at different angles would allow the bar to lock in. So, after constructing the prototype, a test showed the best option. Weights in different areas on the chair simulated a child's weight while the chair rotated during the test, which simulated a

child anywhere from 30 to 100 lbs. The weight bars in the original design needed too much weight (a total of 30 lbs.) to have run effectively with a child over 80 lbs. This option obviously did not work well enough to use. The swing bar, on the other hand, was relatively easy to use and worked much more smoothly. It also did not require the constant addition of weights like the counterbalance bars. Instead, only the distance where the weight was mounted needed adjustment. However, this solution had its own problem. One weight could not accommodate both a smaller child and a larger child. With a larger counterbalance (more than 10 lbs.), the weight, even at the setting closest to the pitch axis, would offset a smaller child (less than 50 lbs.) so much that it overcompensated the shifted pitch axis, but a smaller weight did not have enough weight even at the farthest extension to suit the larger children (greater than 85 lbs.).

In the end, the design allowed three 2.5 lb. weights to be added to the adjustable bar, but narrowed the suitable weight range for a child. The structure would no longer accommodate a child above 85 lbs. The team thought this was reasonable since a child this large could not sit comfortably in the chair.

In conclusion, the team would like to change only a couple things about the prototype:

1. Replace the T-slots.

The chair takes a long enough time to construct without them. The numerous components of the T-slots were the biggest cost for our prototype.

2. Adjust the seat structure.

Originally, the group did not consider using counterweights. Because of this, the chair ended up being more complex than necessary. In fact, a manufactured chair that mounted between the disks might substitute for our whole chair structure. A manufactured chair would save cost, reduce weight, cut construction time, and increase simplicity of the structure.

CONCLUSION

The final design gives more than adequate vestibular stimulation to children two to seven years old. It also has subassembly parts that weigh less than 40 lbs., so each part can ship easily. The total weight of the system does not exceed 500 lbs. The device's total estimated cost sits at \$1700, but the vast amounts of machining required for each part could increase the cost of labor. The team's prototype cost \$2,600, but that includes parts and test weights that a production model would not use.

The final design also meets all of the requirements set forth earlier. It provides for adequate safety, suits a child's needs, and provides a workable solution to the center of gravity problem. Despite the success of the prototype, the design should have significant modifications in order to make a reasonable production system.

ACKNOWLEDGMENTS

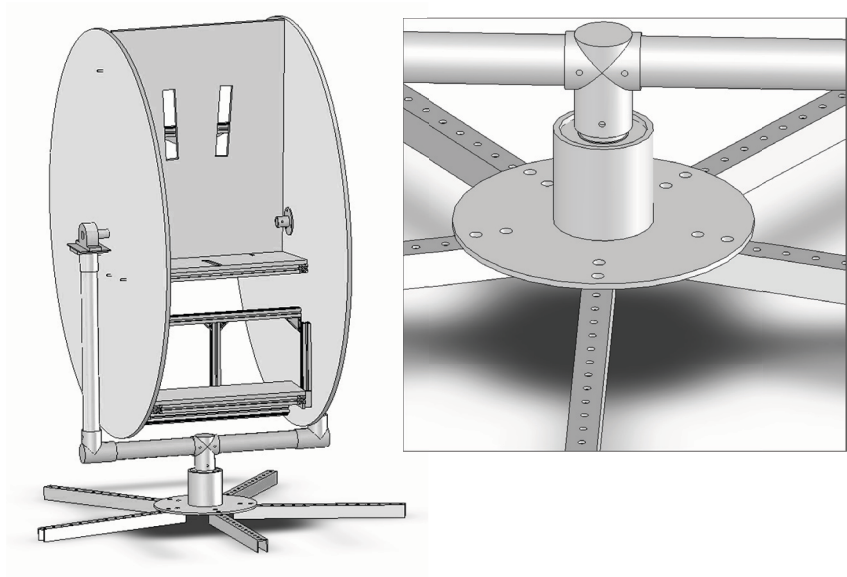
A big thank you is due to both Dr. Brian Self and Kevin Maher, for their valuable insight and guidance. This project would not have gotten as far as it did without their input.

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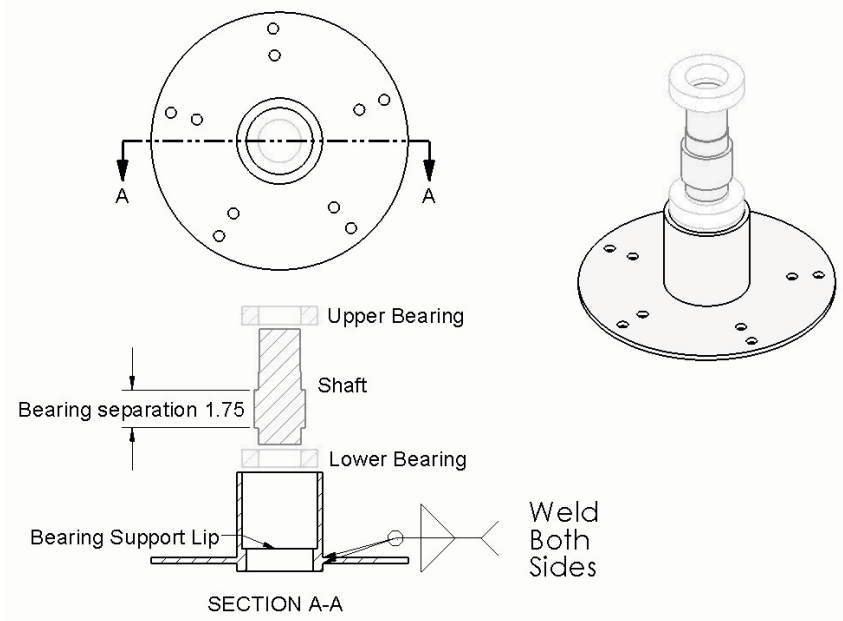
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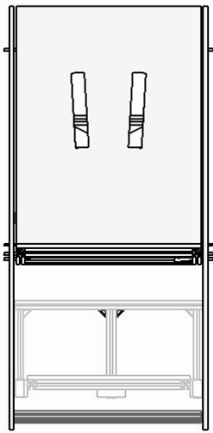
APPENDIX

The following pictures illustrate the final design of the vestibular stimulation device prototype. These pictures do not represent changes made while constructing the prototype, such as the swing bar for a counterbalance weight.

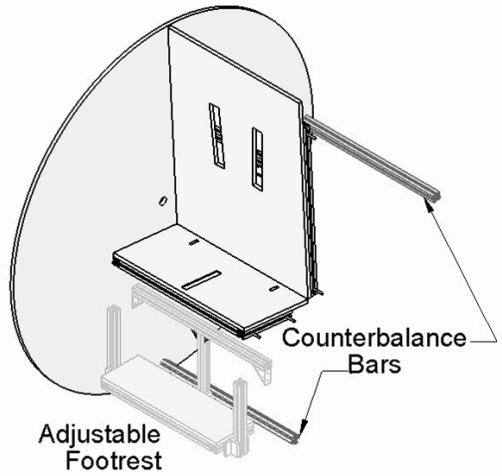


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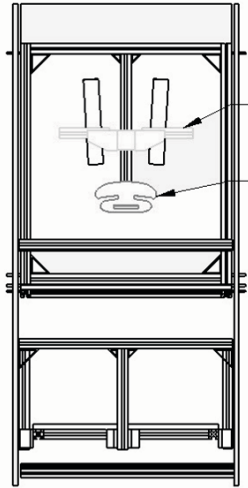


Front



Adjustable Footrest

Counterbalance Bars



Back

Harness Adjustment Slider

Yoke

