Preliminary Report - Somatosensory Stimulation Apparatus for Rodent Cages

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BME 400 - Fall 2017

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Abstract

Many peripheral nerve injuries are a result of amputations, which affect an estimated 185,000 people in the US each year. Prosthetics are continually improving, but a large issue that remains is the patient's lack of tactile perception. Dr. Aaron Dingle is designing a device to solve this problem. The functional outcome of these devices can be assessed in humans by asking the patient questions, but this technique is not an option in animal models. In order to receive functional outcome data from rats, a healthy rat can be trained to respond in a certain way to a somatosensory stimulus. A peripheral nerve can then be surgically severed and the device implanted. The device can then be used to apply what should be recognized as the same somatosensory stimulus the rat was trained with. This project aims to design the somatosensory stimulation device used to train the rats. The device will be able to apply a graded stimulus to at least two limbs individually. The device will consist of a cage for the rat as well as a microcontroller to control the stimulus grade. The proposed final design includes clear plastic cage walls on top with two platforms that vibrate via speaker actuators underneath. The two pieces will be connected using a vibration damping rubber. Fabrication of the device followed by testing with an accelerometer are the next steps for this project. After a working prototype is created, Dr. Dingle will be able to begin his animal testing research.

Introduction

There are 185,000 amputee surgeries every year in the United States[1]. Patients can receive amputations of one or more limbs as well as eyes, teeth, tongue, nose, and more. Of these amputation types, all can lead to phantom limb pain, limb amputation being the most commonly reported source of this pain. Phantom limb pain is a neuropathic pain, often described as a shooting or burning pain, that is caused by the misfiring of the nerves damaged during amputation[2]. 42.2-78.8% of amputees suffer from phantom limb pain either immediately following surgery or years later. Phantom limb pain is currently treated with both pharmacological and nonpharmacological approaches, but due to the lack of a full understanding of the mechanism behind this pain, these treatments are often ineffective[3].

One solution to phantom limb pain that Dr. Aaron Dingle is currently investigating is an electronic interface for peripheral nerves. This electrode could be implanted around the nerve(s) severed during amputation and prevent phantom limb pain while serving as a means to restore the amputee's sense of touch through a prosthetic limb. Dr. Dingle's device is in the animal testing stage of the FDA approval process and he is in need of a device to allow for accurate functionality testing in rat models. Functionality testing for this type of device in humans is straightforward as the researcher can ask the subject if they felt a sensation in their amputated limb and receive a verbal response. In rats, however, a nonverbal method is needed in order to determine the device's functionality.

One common method for receiving device functionality data from rats is to collect data to form a sinusoidal curve of percent correct responses versus stimulation amplitude (Figure 1). This data can be collected by training a healthy rat to respond in a specific way to a certain stimulus and plotting the percent correct responses versus stimulation amplitude after the rat has been trained. For Dr. Dingle's purposes, for example, the rat can be trained to respond by poking his nose in hole on its right side after receiving a vibrational stimulus on its right foot. Ideally, using a large range of vibrational frequencies should then produce a sinusoidal curve of data points. In order to test his device, Dr. Dingle would like to compare the curves of healthy rats and rats with hind limb amputations with his device implanted. Success of his device will be proven by finding similar curves because this indicates that stimulation of the severed nerve with his device feels that same as a vibrational stimulus on the amputated foot of the rat.

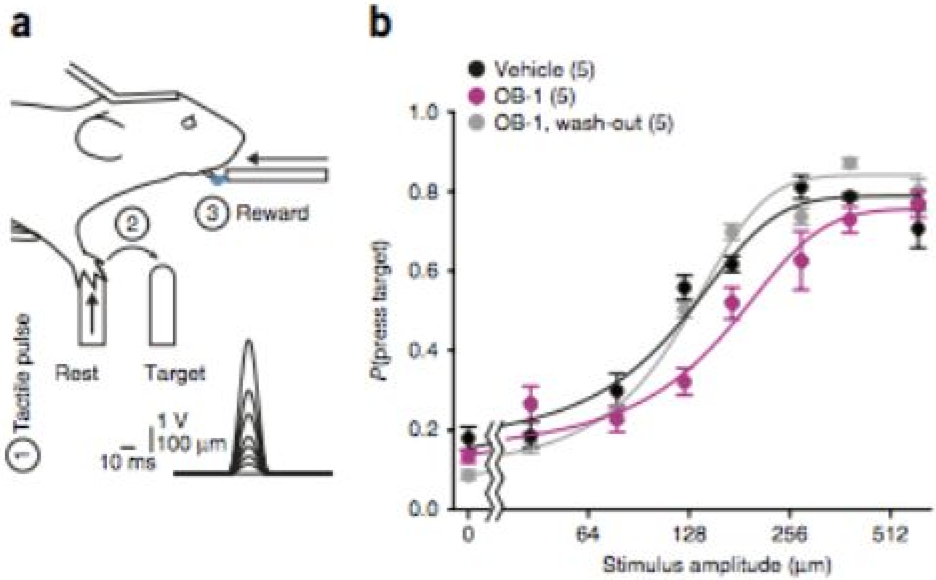

Figure 1. An example of a sinusoidal curve of percent correct response versus stimulation amplitude in trained rats. (a) The experimental setup for obtaining the data 1) The rat receives a tactile pulse stimulus. 2) Upon detection of the stimulus, the rat presses the target button. 3) The rat is rewarded with water for correctly responding to the stimulus. (b) The resulting curves of percent of times the target was pressed vs the stimulus amplitude in this experiment under three different conditions[4].

Current rat training enclosures on the market include a rat testing cage from Coulbourn (Figure 2). Cages such as these come with no floor or wall panels, but accommodate additional training modules that are sold separately. These training modules include a shocking floor and nose poke holes with optic and olfactory stimuli[5]. While a shocking floor could provide stimulus to a rat's hindlimbs, it does not allow for isolation of the stimulus onto a single limb. This detail is critical for testing efficacy of Dr. Dingle's device.

Figure 2. Rat test cage from Coulbourn. This enclosure accommodates different floors and wall panels for different types of rat training[5].

In order to perform this type of rat testing, a device is needed that can stimulate a single rat hindlimb at a large range of frequencies without causing any residual artifacts of the stimulus that may lead the rat to give the correct response without proper functioning of Dr. Dingle's device. For example, the stimulus must be completely isolated to one hindlimb so that vibration cannot also be felt in the other, healthy leg at the same time. There must also not be any noise differentiation between stimulus levels so that the rat cannot form associations and respond based on auditory stimulation.

In addition to the part of the device that will provide the stimulation, the device must also include a cage in which the rats can be trained. This entails a cage that allows for visibility of the rat. This cage should restrict non-experimental movement, but not limit the rat's ability to respond to the stimulus. In order to do this, the cage should include three holes at nose-height of a rearing rat so the rat can poke its nose in the appropriate hole and receive its reward (Figure 3).

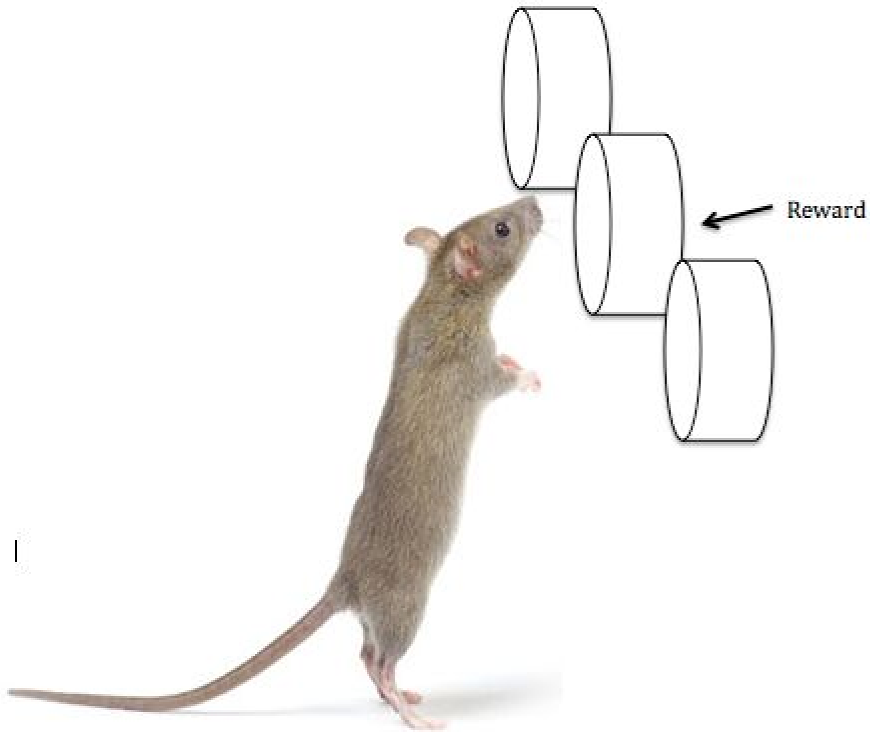

Figure 3. The rearing rat receives its reward by poking its nose through one of the three holes in the cage wall [6].

Background

In order to elicit a response in a rat, the somatosensory system must transmit the stimulus from the peripheral nervous system neurons, through the central nervous system to the brain where a response action can be determined. The somatosensory system has different receptor cells for each modality of stimulation. Both humans and rats have mechanoreceptors, thermoreceptors, proprioceptors, pain receptors, and chemoreceptors in the body. As explained later in this report, mechanoreceptors will be the focus of this device as a vibrational stimulus will be used in the device. In the skin, humans and rats have two main cell types that sense vibrational stimulation (Figure 4). Merkel cells are closest to the surface of the skin and sense low frequency vibrations of about 5-15 Hz. Slightly deeper in the skin are tactile corpuscles, which sense a slightly higher frequency range of about 10-50 Hz [7].

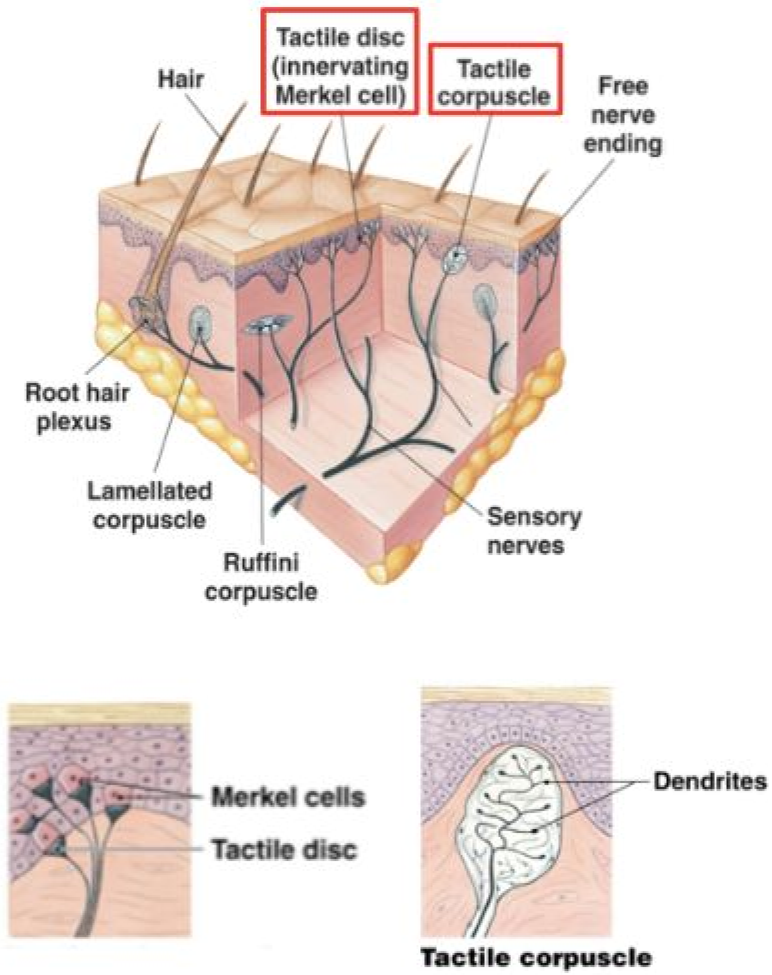

Figure 4. Mechanoreceptors in the skin. Merkel cells and tactile corpuscles sense low frequency vibrations on the surface of the skin and send the information to the brain via the somatosensory system[7].

Lamellar corpuscles can sense higher frequencies up to 250 Hz, but these cells will not be the focus of this project due to the need to isolate the vibration to a single hindlimb. Rat bodies are able to attenuate vibrational frequencies up to 31-50 Hz. Above this range, the entire body of the rat begins to vibrate at the applied frequency [8]. For the purpose of this project, all parts of the body except for the stimulated hindlimb must remain isolated from the vibration.

The rats that will be used by Dr. Dingle in his experimentation are adult Lewis rats ranging in size between 250-350 g. These rats are commonly used as animal models due to their physiological similarities to humans as well as their mild temperament.

The device designed must provide a means for training rats for many purposes including Dr. Dingle's planned protocol. To achieve this, the device must provide isolated stimulation to each rat hindlimb. The stimulus must be graded and controlled with a microcontroller to achieve a desired frequency in the range of 5-50 Hz with an accuracy of +/- 0.5 Hz. The design must include a cage that allows a rat to respond to the applied stimulus. This cage and stimulation apparatus must weigh under five pounds for easy storage and setup. In addition to Dr. Dingle's electrode implantation protocol, this device could be used in other applications such as to test for the efficacy of nerve regeneration in rats.

Preliminary Designs

When given the parameters for the design of this device, Dr. Dingle stated that it must provide stimulation to the hindlimbs of the rat. Before creating design ideas to evaluate using the design matrix, the team had to choose what type of stimulation the device was going to deliver. The stimulation modalities that were considered are as follows: vibration, electrical, temperature, and pressure. Electrical stimulation was not used because it was too similar to the electrode therapy that will be used on the rats. This would be a problem because the rat could possibly confuse the stimulation that it is supposed to respond to with the therapy that it received for nerve regeneration. Temperature was ruled out because it is not instantaneous and had the potential to harm the rat if it was unable to sense a high temperature. Finally, pressure was not used because it was also not instantaneous as well as the method of implication that would be used was vulnerable to damage by the rat if it began to chew it. Ultimately, the team decided to use vibration as the method of stimulation. One method of implementing the vibration that was considered was to attach a cuff to the foot of the rat. Due to the fact that this method could restrict the rat's movement and that it would be vulnerable to chewing, the vibrating cuff was ruled out. The team decided that a platform with unilateral vibration would be the best method for stimulation because it does not limit the rat's movement, is not vulnerable to chewing, and provides a high level of isolation for the stimulation.

Once a method of stimulation had been decided, the team used two separate design matrices to evaluate what type of unilateral motor would be used to provide the stimulus and the interface of the motor and cage.

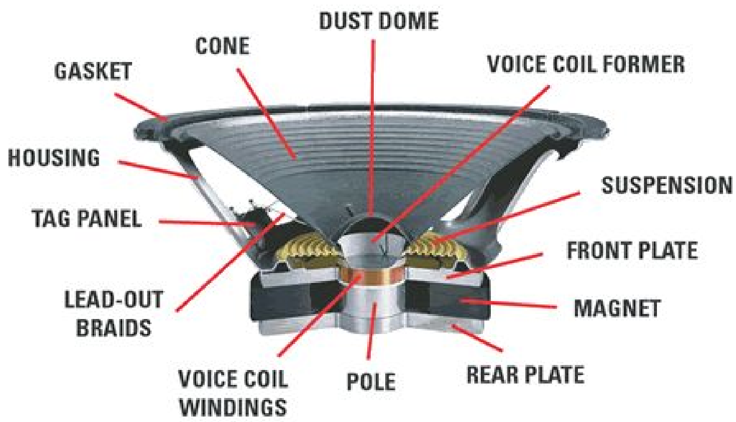

Figure 5. Speaker actuator diagram [10]

The first design considered for the unilateral motor was the actuator from a speaker. Figure 5 illustrates the anatomy of a basic speaker, showing which parts would be used in the design. In order to utilize this device the cone, housing and dust dome would be removed. The platform that goes to the floor of the cage would then be attached to top of the voice coil former. This speaker would allow us to easily output our frequency range of 5 - 50 Hz.

Figure 6. Solenoid motor that would be used for the design [9]

The final motor that was considered to deliver the unilateral vibration for stimulation of the rat was this solenoid motor. An example of this motor is displayed in Figure 6. The driving shaft of the solenoid will push and pull based on the directionality of the current that is provided to the coil inside of the solenoid. With the platform attached to the driving shaft, this push and pull movement will create the vibration that is desired.

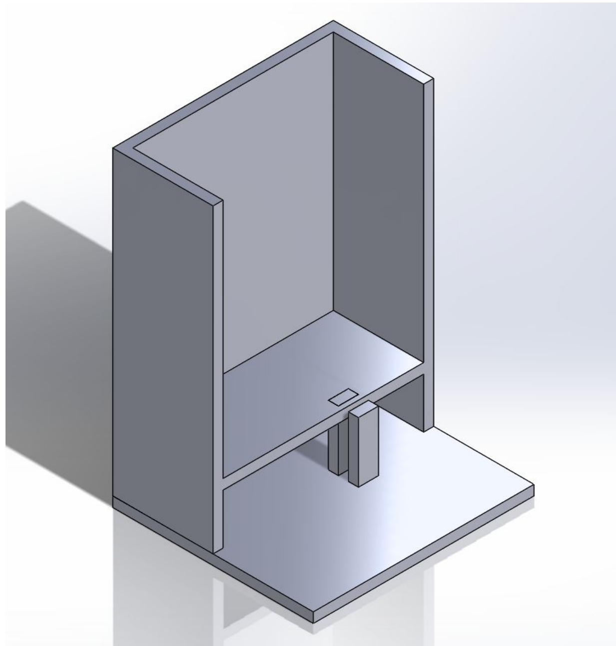

Figure 7. Cross sectional view of the cage with a connected motor-base interface. The bars that protrude from the base represent the motor and platform that will be used.

The next designs that will be evaluated are the motor-cage interface designs. The first design with a connected interface can be seen in Figure 7. This design will feature walls made out of clear polycarbonate plastic to allow for easy viewing of the rat during testing and training. The bottom section, containing the motors and electrical components, will be attached to the main body of the cage using a vibration damping rubber. This material was used in order to isolate the vibration of each individual motor while maintaining the rigidity of the cage to allow for easy use and stability.

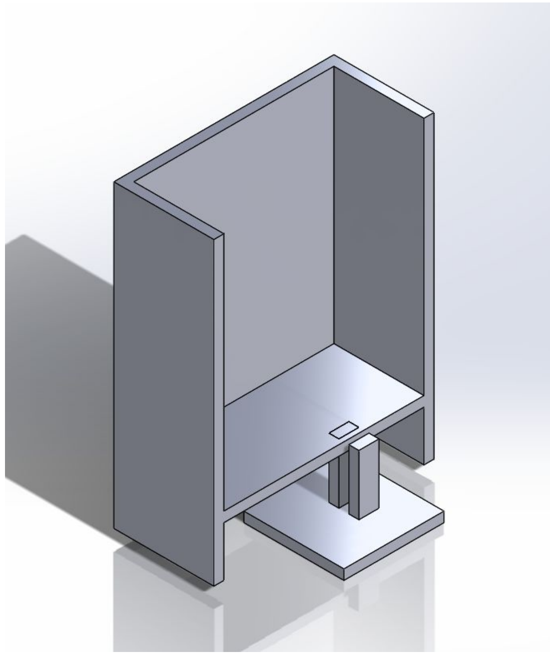

Figure 8. Cross sectional view of the cage with a disconnected motor-base interface. The bars that protrude from the base represent the motor and platform that will be used.

The final design that was considered for the cage-motor interface features a base, containing the speakers and electronic components, that is completely disconnected from the main body of the cage. The base holding the electronics is to be made out of a heavy metal. This will allow the motors to vibrate freely and be isolated from the rest of the cage. This design ensures that the vibration does not propagate to other sensitive areas of the rat, eliciting a false response.

Preliminary Design Evaluation

Since the project has two distinct design components that needed to be decided on, the team made two different design matrices. The first one compares the options for the vibration source and the latter compares the choices for the cage-motor interface.

Vibration Source				
Design Criteria (weight)	Solenoid Motor		Speaker Actuator	
Force (20)	4/5	16	5/5	20
Accuracy (15)	4/5	12	5/5	15
Durability (10)	4/5	8	2/5	4
Amplitude (5)	4/5	4	5/5	5
Total	**40**		**44**	

Table 1: Preliminary design matrix for the vibration source.

Force of the vibrational motor is defined as the Newtons of force generated by the motor. This is weighted the highest because the force must be less than 3 Newtons to ensure the comfort and safety of the rat. The speaker actuator received a score of 5/5 because it generates a force of less than one Newton. The solenoid motor received a 4/5 because it generates a force of 2 Newtons. This is still well below the threshold, which justifies its rating. This is still higher than the speaker, so it could not receive a perfect score.

Accuracy is defined as the ability for the motor to achieve the desired frequency range of 5-60Hz. The motor also has to be able to maintain the exact frequency +/- 0.5Hz. Accuracy was weighted second highest because the goal of the project is to stimulate the rat's hindlimbs at a specific desired frequency. The speaker actuator received a perfect score of 5/5 because it is able to successfully output the desired frequency range. The solenoid motor received a lower score of ⅘ because we were not able to find any literature proving that the solenoid would be able to produce the higher frequencies within our range.

Durability is defined as the length of time the motor will remain functional in the device. This was weighted lower because both components are inexpensive and would be able to be replaced. The solenoid motor was given a 4/5 because it will be used in the device as intended, but it's low price indicates that it may not be the most reliable. The speaker actuator was given a

2/5 because it is inexpensive and the device will utilize the motor in a manner that was not originally intended.

Amplitude is the measure of the displacement of the vibrations caused by the source. Although other categories were given higher precedence, this is important because too large of a displacement could agitate or irritate the rat. The solenoid motor was given a 4/5 because they tend to have larger amplitudes ranging from 1-4.5mm. The speaker actuator received a 5/5 because they have much smaller amplitudes, making the concern for the rat's comfort due to the displacement virtually nonexistent.

Cage - Motor Interface				
Design Criteria (weight)	Connected		Disconnected	
Stabilization (20)	5/5	20	3/5	12
Isolation (20)	3/5	12	4/5	16
Ease of Use (10)	5/5	10	3/5	6
Total	**42**		**34**	

Table 2: Preliminary design matrix for the cage motor interface.

Stabilization of the cage-motor interface is defined as the ability for the cage to stay aligned with the motor platforms. This is weighted as one of the most important factors because if the motor platforms don't stay centered in the cage openings, it will potentially cause the rat to step off of the platform and/or vibrate the entire cage floor. The connected cage design was given a 5/5 because the cage will be held in place over the motors via the shock absorbing rubber base. The disconnected design was given a 3/5 because the motors will be weighted down with a heavy base, but will not be rigidly attached to the cage.

Isolation is defined as the ability for each vibrating motor platform to be completely unaffected by the other motor's vibration. This is also weighted as one of the most important factors because the goal of the project is to be able to apply stimulation to a single limb at a time. The connected cage design was given a 3/5 because the shock absorbing base will absorb motion, but there is still potential for the vibration to be transmitted through the connection of the motors to the cage. The disconnected design was given a 4/5 because vibration will not be directly transmitted between the cage and the motors, however, because they will both be sitting on the same surface, there is potential for the vibration to transmit through this interface.

Ease of use is defined as the amount of time and effort required to store, move, and set up the device. This was weighted lower because the device can still be successful even if it takes some time to set up. The connected design was given a 5/5 because it is all one piece that can be easily moved and stored and requires no accurate set up. The disconnected design was given a 3/5 because it is two separate pieces that must be properly aligned before use.

Proposed Final Design

The proposed final design will feature the two winners from both design matrices. A speaker actuator will be used for the vibration source along with the connected cage-motor interface. A solidworks drawing for the connected cage-motor interface with dimension is included below. In addition, a system diagram of the electrical components for the device is also included.

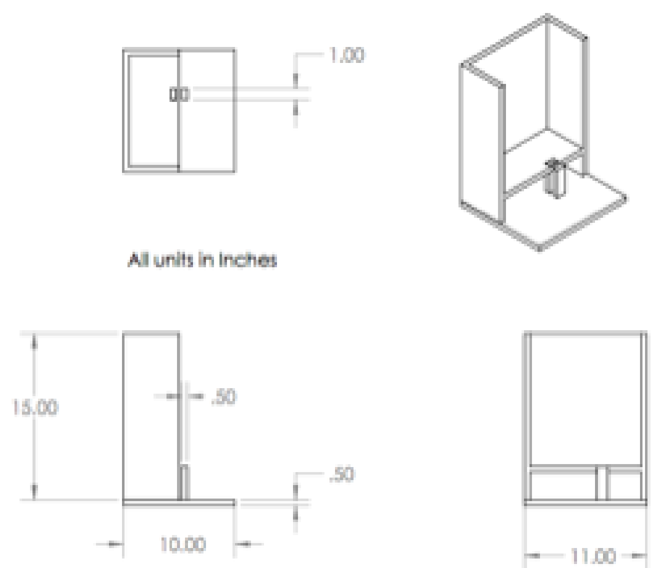

Figure 9: Solidworks drawing of the connected cage-motor interface chosen for the proposed final design. Different views with the dimensions (in inches) are shown.

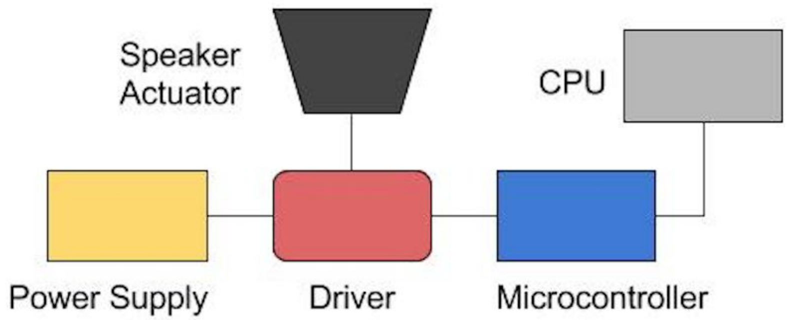

Figure 10: This system diagram shows the basics of the electrical components needed in the device.

The microcontroller is the main component of the electronics part of the design. It will provide the waveform for the vibrations at a specific frequency. The microcontroller is limited to certain voltages and currents. This may not be sufficient to drive the speaker actuator. For example, the popular Arduino Uno that the team has considered is limited to a max 200 mA current. Therefore, a driver may be needed. The driver acts like an amplifier to the signal, providing sufficient voltage and current to drive the vibration source. It will need its own power supply to do so. The driver then will send the signal to the speaker actuators which will provide the vibration stimulus.

The last part of the system diagram is called CPU for simplicity. This part is responsible for supplying power to the microcontroller as well as conveying the desired frequency and the desired limbs for stimulation. The microcontroller can easily be powered by plugging it into a computer, but transmitting the desired frequencies/limbs is more complicated. The simplest way would be to hard code the stimulus parameters on the computer, but this required the code to be edited and uploaded to the microcontroller each time a parameter is changed. Since a microcontroller is an integrated device, there is program console from which the inputs can be easily updated. The team will look into ways to easily and efficiently update the stimulus parameters, such as through other electronic/circuit components.

Fabrication/Development Process

Materials

The materials needed for the cage are polycarbonate plastics, highly damping rubber, and caulk. The clear polycarbonate plastic will be used for the walls and the floor of the cage. This will allow users to easily see the rats during experiments. The highly damping rubber will be used for the connection between the cage and the vibration source. This will help to isolate the vibrations and ensure they are not transmitter to the rest of the cage. The caulk will be used to seal the edges of the cage. The caulk used must be safe for the rat.

The materials needed for the mechanical and electrical components of the device are speakers, wires, a microcontroller, a driver, and a power supply. The speakers will be altered so that their actuators can be used to provide the vibration source. The microcontroller will be responsible for providing the output waveform at the desired frequency. The driver will increase the voltage and current from the microcontroller so that the signal can drive the speaker actuators. In order to do this, the driver will require its own power supply as well. Traditional wires will be used to connect the pieces, since blocking out noise is not a concern for this application. While this lists all the pieces of the device, the team still needs to decide on specific parts. In addition, as discussed in the Proposed Final Prototype above, a component that will power the microcontroller and convey the stimulus parameters to the microcontroller is needed. However, the team has not determined how this will be done at this point.

Methods

The first step in fabricating our prototype is to have the members of the team renew their green pass credentials. Once the passes have been renewed, the team will use the equipment in the machine shop to cut out the pieces of polycarbonate that will make up the cage. The polycarbonate cage will be assembled using caulk. The cage will be assembled in two pieces, top and bottom. The bottom will be start with a 10 x 11 in piece of polycarbonate, which will then be covered in the rubber damping material. Next, the following parts must be removed from the speaker to allow for attachment of the platform: cone, dust dome, and housing. The platform will then be attached to the voice coil formers. All of the electronic components will then be connected, tested, and fixed to the damping rubber. Finally, two pieces of the cage will be screwed together. Screwing the pieces together allows for easy removal of the base in case any adjustments must be made to the electronic components.

Final Prototype

The final prototype will consist of two modified speaker actuators fed by a driver and power supply and controlled using a microcontroller. All of the components will we enclosed in a group-made clear polycarbonate cage to allow for easy viewing of the rat during training and testing.

Testing

The first step of the testing will be pretty informal and will be done by the group members. For example, the team will ensure the correct limb is stimulated at the correct time and that the stimulus is isolated from the rest of the device. These tests will be done to make sure the device is working as specified by the client.

The second part of the testing will involve verifying the frequency outputs. The team will need a way to check if the vibrations are actually at the desired frequencies. However, this is not an easy task. This team hopes to use an accelerometer in order to do this. Accelerometers are a good choice for this because low frequency vibration measurements is one of their primary uses. Another way to test the frequencies would be to use a high speed cameras. Dr. Nimunkar is doing similar testing where he is trying to verify the frequencies of a moving arm using cameras, and he has discussed the difficulties with the team, especially at higher frequencies. Therefore, the team thinks this might not be a feasible option. Through this testing, the team hopes to verify that the vibration frequencies are within +/- 0.5 Hz and range from 5-50 Hz. Success for isolation is defined as a reading of less than 5 Hz on one platform while the other platform is vibrating at the maximum frequency of 50 Hz.

Results

Due to the fact that this is a first semester project, no initial testing has been done on a similar device. The anticipated results would include the device being able to accurately produce the correct frequency that is given to it through the microcontroller. At this point in time, the team does not have a working prototype, so no testing has been done. Results will be reported as soon as data has been obtained.

Discussion

After fabricating and testing the device, the outcome that the team hopes for would be that the device is able to accurately produce the desired frequency range. From there Dr. Dingle will be able to conduct his desired testing of the nerve regenerating electrode therapy in the rats. With the help of the stimulation cage, Dr. Dingle will be able to determine whether the electrode therapy is able to successfully replace the sense of touch in a rat's amputated hindlimb. This result would have huge implications for humans because it would allow amputees to restore some of the sensory function that they had in their original limb while improving the phantom limb pain that affects a high percentage of amputees. This restored sense would drastically increase many amputees quality of life going forward.

Conclusion

Peripheral nerve injuries are common, debilitating and costly. Approximately 2.8%-5% of all trauma patients in the US sustain such an injury. Many peripheral nerve injuries are a result of amputations, which affect an estimated 185,000 people in the US each year. Prosthetics are continually improving, but a large issue that remains is the patient's lack of tactile perception. Many researchers, including Dr. Aaron Dingle, are designing devices to solve this problem. The functional outcome of these devices can be assessed in humans by asking the patient questions, but this technique is not an option in animal models. Rats are commonly used as animal models as a precursor to human subject testing. In order to receive functional outcome data from rats, a healthy rat can be trained to respond in a certain way to a somatosensory stimulus. A peripheral nerve can then be surgically cut and the novel device implanted. The device can then be used to apply what should be recognized as the same somatosensory stimulus the rat was trained with. Observations on the percent of correct reactions can be used to determine success.

This project aims to design the somatosensory stimulation device used to train the rats. The device will be able to apply a graded stimulus to at least two limbs individually. The device will consist of a cage for the rat as well as a microcontroller and CPU to view and control the stimulus grade. Current rat training enclosures do not offer stimulation that can be isolated to the individual hindlimbs. The proposed final design includes clear plastic cage walls on top with two platforms underneath that vibrate via speaker actuators with a driver and power supply. A rearing rat will stand on these platforms during training. The two pieces will be connected using a vibration damping rubber. An accelerometer will be used to verify that the platforms can vibrate in a range of 5-50 Hz with an accuracy of +/- 0.5 Hz and that the vibration on each platform is completely isolated from the other. Fabrication of the device followed by testing are the next steps for this project. After a working prototype is created, Dr. Dingle will be able to begin his animal testing research.

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Appendix I. PDS

Somatosensory Stimulation Apparatus for Rodent Cages
Product Design Specification

Function

Rats are commonly used as animal models as a precursor to human subject testing. In order to receive functional outcome data from rats, they can be trained to respond in a certain way to a somatosensory stimulus. This project aims to design a somatosensory stimulation device used to train rats. Our client needs this device to gauge the efficacy of their electrodes, which provide electrical stimulation to aid and tactile perception nerve regeneration in the hindlimbs of rats. The device should be able to apply an individual graded stimulus to at least two limbs, keeping the stimulus isolated to each limb. The device will consist of a cage or cage insert as well as a microcontroller/complementary circuitry to control the timing and grade of the stimulus.

Client Requirements

- Stimulate the two hind limbs of the rat independently and extend the stimulation to the front limbs if possible
- Avoid using electrical stimulation since it might interfere with the electrodes
- Incorporate a graded stimulation to the rat
- Create a system that allows the rat to respond uniquely to different levels of stimulation
- The stimulation must be applied to the rat in the confinement of a cage that does not restrict the rat's movement

Physical and Operational Characteristics

a. Performance requirements: The device will need to comfortably fit a 250-350g Lewis rat. There should be 2-4 individual locations for stimulus to be supplied to the limbs of the rats. The device will be used multiple times in a row for up to 60 minutes at a time until the rat has 50 correct responses. It needs to be able to accommodate testing on addition rats afterwards. The device will have a permanent power supply (most likely a laptop), so battery life is not a concern.

b. Safety: Rats must not be harmed during use of the device. This requires standard electrical safety standards such as eliminating exposed wires. The vibrational stimulus must range from 5-50 Hz in order to stay isolated on the rat hindlimb. If the device has parts that get attached to the limbs, it must not excessively restrict the rats motion.

c. Accuracy and Reliability: The device must be able to provide stimulus in a precise, repeatable manner. Initially, the team will focus on obtaining a single, consistent stimulus, but eventually the client would like graded levels of stimuli. Success of the device is first determined by the ability to generate an accurate and reliable signal along with a system that allows for different levels of response by the rat. Success will also be determined by the ability to fit a sigmoidal curve to the data collected by plotting percent correct response vs. stimulus amplitude.

d. Life in Service: The device should be used on the rat for 60 mins at a time, until the rat achieves 50 correct responses. It must be able to undergo many consecutive trials for several days in a row. The device will be plugged in, so operating life will not be an issue.

e. Shelf Life: The device will be stored in a temperate, dry lab environment. The device itself does not have a shelf life, but like any other device, as technology improves, the device may become outdated.

f. Operating Environment: The device will be used in a lab environment, which includes normal room temperature, pressure, and humidity. The largest concern is ensuring that the electrical and mechanical components stay dry and out of reach from the rat to ensure that it does not damage the components.

g. Ergonomics: The vibrational stimulus must range from 5-50 Hz in order to stay isolated on the rat hindlimb. If vibration is the stimulus, the noise caused by the vibration must be inaudible or another noise must be produced so that the auditory stimulus between all stimulation amplitudes is the same. The device should be able to accommodate any small variations in the size of the rats, and must not cause them any discomfort to avoid false stimulus responses.

h. Size: The cage must be 10inX12inX12in. There are no restrictions of the size of the circuitry/ complementary components outside of the cage.

i. Weight: The device will be used on a table or a lab bench, so weight is not a major concern. Nevertheless, a target weight of less than 5 lbs will allow researchers to easily carry, move, and store the device.

j. Materials: No material should be used that could potentially cause irritation to the rats. The cage floor and walls should be made out of clear polycarbonate. For the components outside the cage, there are no material restrictions.

k. Aesthetics, Appearance, and Finish:The cage should be made from a clear plastic to allow for observation of the rat during the training and testing periods. The device is for testing purposes so the aesthetics/ appearance is not the primary concern.

Production Characteristics

a. Quantity: The client only needs one device, but it must provide multiple stimulations for testing

b. Target Product Cost: A max budget of $1000 was given. The client gave the team access to the lab's Quartzy group, which will allow us to easily get supplies ordered. There are no existing products on the market to compare with the cost of this project.

Miscellaneous

a. Standards and Specifications: The device must be consistent with the Animal Welfare Act (1966). This act regulates the treatment of animals in research, exhibition, transportation, and by dealers. We must also follow normal standards for electrical safety.

b. Customer: Client likes idea of having a vibrating floor in the cage and believes it will be easy to train the rats to respond toward this type of stimulation. However, they are open to other potential sources of stimulation.

c. Patient-related concerns: Device must be able to be sterilized. This can be done using by wiping the device with cleaning solution after each use.

d. Competition: There are a variety of companies out there that create product for rat testing, such as Vulintus and Harvard Apparatus. None of these companies make a product that performs this type of specific hind leg stimulation for research on nerve regeneration.